

हरियाणा के सोनीपत जिले की राय ब्लॉक में संसाधन संरक्षण
प्रौद्योगिकियों का मिट्टी के संरचनात्मक गुणों पर प्रभाव

**Impact of Resource Conservation technologies on soil structural
properties in Rai block of Sonapat district of Haryana**

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**DIVISION OF AGRICULTURAL PHYSICS
INDIAN AGRICULTURAL RESEARCH INSTITUTE
NEW DELHI – 110012**

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**Impact of Resource Conservation technologies on soil structural
properties in Rai block of Sonapat district of Haryana**

A Thesis

By

MUKHTAR AHMED

**Submitted to the Faculty of Post Graduate School,
Indian Agricultural Research Institute, New Delhi,
in partial fulfillment of the requirements
for the award of the degree of**

MASTER OF SCIENCE

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CERTIFICATE

This is to certify that the thesis entitled “**Impact of Resource Conservation technologies on soil structural properties in Rai block of Sonapat district of Haryana**” submitted to the Post Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfillment of the requirements for the award of the degree of **Master of Science in Agricultural Physics**, embodies the results of *bonafide* research work carried out by **Mr. Mukhtar Ahmed** under my supervision and guidance, and that no part of the thesis has been submitted by him for any other degree or diploma.

It is further certified that any help or information that has been availed of in this connection is duly acknowledge by him.

Date: 30 june 2012
Place: New Delhi-12

[Dr. (Ms.) Pramila Aggarwal]
Chairperson, Advisory Committee

Dedicated
to
My Dear Parents
&
My Chairperson
&
My Friends

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(Mukhtar Ahmed)

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1. GENERAL INTRODUCTION

Intensive cultivation of agricultural soils can lead to deterioration in soil structure and other soil physical properties and consequently reduction in crop productivity. The combination of inversive soil tilling and more intensive cropping methods increased the rate of soil degradation, *e.g.* deterioration of soil structure, accelerated erosion, depletion of soil organic matter and fertility and disrupted cycles of water, organic carbon and plant nutrients (Lal, 1993). Soil degradation in turn was found to be detrimental to long-term soil productivity (Larson *et al.*, 1983, Norwood *et al.*, 1990). Thus the need for tillage has been questioned in the last few decades because of the excessive erosion from farmland after tillage. Runoff from agricultural land may carry sediments, chemical fertilizers and pesticides, all of which can degrade water quality and upset the ecosystems of streams, lakes, reservoirs and rivers.

In the IGP, new resource conserving technologies for proper land and water management are being developed for enhancing crop productivity. Resource-conserving technologies are defined here as any practice that improves the efficiency of use of natural resources, including water, air, fossil fuels, soils, inputs and people. The conservation of resources (land, water, energy) saves cost of water, energy and protects environment while leading to improved productivity on sustainable basis. Targeting the resource conserving technologies offers newer opportunities of better livelihood for the resource poor small and marginal farmers. At the same time, these technologies are generating alternative sources of productivity growth through diversification and intensification of production systems.

A healthy soil will is less erodible and more productive. The soil erodibility which is an indicator of soil structural stability against erosion depends primarily on the physical characteristics of the soils viz., nature and size of soil aggregates, organic matter content, infiltration characteristics and particle size distribution. Soil structure influences soil physical, chemical and biological processes. It is critical for soil fertility and transport of water and contaminants through the unsaturated zone. As the functional unit of soil structure, soil aggregates are important for maintaining soil porosity and providing stability against soil erosion. Soil aggregate is the pool of soil nutrients and the habitat of soil microorganism (Six *et al.*, 2004). The distribution and space arrangement of different fraction aggregates determine the soil pore types and

porosity, and also the soil hydrodynamic properties. The content and distribution of water stable aggregates reflect the stability of soil structure and erosion resistant ability. Distribution of aggregates is a consequence of soil structure and is a potentially useful way of expressing structure quantitatively. Therefore, the change in the distribution and stability of soil aggregates can reveal the influence of conservation tillage measures on soil quality. These physical characteristics of soils are much affected by the land use and land management practices. Soil erodibility can be evaluated by using runoff plots, which is quite expensive, time consuming and is not feasible at all places. Best way to estimate soil erodibility is by using various soil erodibility indices based on soil physical characteristics. Erodibility indices like dispersion ratio, clay ratio, modified clay ratio and erosion ratio have been employed by different workers to assess the soil erodibility / structural stability.

In literature very little work has been reported showing the long term effect of different soil management practices on soil structural stability. Hence the present study was conducted in farmer's fields in different blocks of Sonapat district of Haryana (part of trans-Indogangetic plain). A survey was conducted in farmer's fields that were already using such conservation technologies from past several years and measurement of important and relevant soil structural properties was carried out. These measurements were used for computing various structural/ erodibility indices for monitoring the impact of these RCT's on soil structural stability, overall soil physical health and productivity of land.

Hence, the objectives of the proposed study were

1. To compute soil structural indices under different resource conservation technologies
2. To study impact of structural indices on crop productivity

2. BACKGROUND

2.1 Resource conservation technology

In India's rice–wheat systems, adoption of ZT is primarily limited to the wheat crop and concentrated in the NW IGP. To date, the most successful resource conserving technology in the rice–wheat systems has been zero-tillage wheat, particularly in the Indian IGP (RWC, 2004). Zero tillage (ZT) is also known as zero till, no till, direct seeding and direct drilling (Erenstein *et al.*, 2007b). The prevailing ZT technology in the IGP uses a tractor drawn zero-till-seed drill to seed wheat directly into unploughed fields with a single pass of the tractor. The typical ZT drill has inverted T openers and opens a number (6–13) of narrow slits for placing seed and fertilizers at the depth of 7.5–10 cm into the soil (Mehla *et al.*, 2000). Most of the available literature relates to the North western (NW) IGP in India–Punjab, Haryana, Uttaranchal (terai) and Western Uttar Pradesh (WUP) which are characterized by areas of intensive agriculture (Narang and Virmani, 2001). The use of ZT in wheat opens the scope for new technologies including the application of ZT to other crops (e.g. pulses and cereals) and permanent beds. ZT also has the potential of increasing cropping intensity and diversity in selected areas of the IGP (e.g. moving towards double cropping in rice–fallow systems, introducing triple cropping in rice–wheat systems).

Ortega *et al.*, (2006) observed that the planting system on permanent beds reduces the operational costs up to 40% and enhances physical and biological soil quality parameters. The soil dispersion index was less for PB, all residue retained as stubble, indicating that soil aggregates were greater in size and more stable for this treatment.

Due to regional differences in climate conditions and soils, there is no universal tillage or cropping system that is best for all situations. Nevertheless, changes in soil structure could affect the relative success of conservation tillage (Karunatilake *et al.*, 2000). Studies in Canadian brown and dark brown soil zones showed that the effects of tillage systems on yields of barley, winter wheat and spring wheat varied from year to year but were, on average, equal (Care foot *et al.*, 1990a, 1990b, Brandt, 1992, Larney and Lindwall, 1994). In the black and gray soil zones of Western Canada, yield increases with no tillage over conventional tillage varied from 0 to 23% for barley, spring and winter wheat, canola and field pea (Stobbe *et al.*,

1970, Arshad *et al.*, 1994, Borstlap and Entz, 1994). In the North Central and North-eastern USA weather and soil type strongly affected the relative success of reduced and no-till methods (Johnson and Lowery, 1985, Griffith *et al.*, 1986, La1 *et al.*, 1989, Cox *et al.*, 1990). In general, it has been determined that well-drained soils, light to medium in texture with a low humus content, respond best to bed planting (Butorac, 1994). The most obvious advantage of reduced tillage from an environmental view point is its role in minimizing the risk of erosion (Riley *et al.*, 1994). Further expansion of conservation tillage on highly erodible land will result in a smaller impact on the environment and an increase in social benefits; nevertheless, the expected gains are likely to be modest (Uri *et al.*, 1998).

2.2 Structural indices

Soil structure can be viewed as the arrangement of primary soil particles into hierarchical structural units identified on the basis of failure zones of different strengths (Hadas, 1987, Kay, 1990). The combination and arrangement of secondary soil units and voids forms a continuous spatial network known as the soil matrix, soil fabric or soil structure (Oades, 1984). Dexter (1988) defined soil structure as the spatial heterogeneity of different components or properties of the soil. Soil particles that cohere to each other more than to other surrounding particles are called aggregates or peds and their boundaries are defined by planes of weakness surrounding a unit of soil without internal shrinkage. Regardless of their origin, all soil structural units can be characterized by their size, shape and surface roughness. Size is commonly used in relation to agronomic and environmental processes. Another measurement used to characterize the soil matrix is structural stability or the ability of the soil to retain its arrangement of solids and void space after the application of a mechanical stress. Structural stability is often measured as the stability of soil fragments exposed to stresses. Soil structural stability and aggregate or fragment stability are often considered synonymous. However, aggregates are normally more stable than the bulk soil (Horn, 1990). The presence of unstable soil structural units favors the detachment of soil particles and the formation of crusts that impede normal shoot elongation and establishment of seedlings. Least limiting water range (LLWR) (an indicator of soil structural stability) was found to be wider under bed than under conventional planting which indicated the superiority of bed planting over conventional planting (Aggarwal *et al.*, 2004, Aggarwal *et al.*, 2006) in terms of structural stability and plant water availability. (Pagliai *et al.*, 2005) observed that

aggregates were less stable in ploughed soils which resulted in more pronounced tendency to form surface crust compared with soils under minimum tillage and ripper sub soiling.

Soil erodibility, susceptibility of the soil to erosion, is mainly a function of soil structural stability. The susceptibility of the soil to erosion processes is reduced where structural stability is high because the formation of crusts and the separation of soil particles are reduced. In the presence of coarse soil structural units runoff and sediment losses are generally reduced (Deizman *et al.*, 1987). Wind erosion is directly influenced by the size, shape, density and mechanical stability of surface soil structural units (Skidmore *et al.*, 1994). Increasing the cloddiness of the soil surface reduces wind erodibility. Resistance to wind erosion is positively related to the percentage of dry soil structural units greater than 0.84 mm (Chepil, 1933).

A combination of aggregate sizes and stabilities are needed for ‘ideal’ soil function and quality. Hence, a weighted factor based on the interactions between soil aggregation and soil function which may better address management impacts was developed and termed as whole soil stability index (WSSI) (Nichols, 2011). The WSSI methodology outlined here uses dry aggregate size distribution and water-stable aggregation (WSA) as variables along with constants which are quantitative surrogates for the qualitative benefits conveyed by different aggregate sizes. Dry aggregate size distribution measures the amount of aggregates formed but does not address the stability of these aggregates whereas WSA is used to determine the stability of these aggregates. Other methodology attempts to separate aggregate formation from aggregate stabilization by differentiating between unstable and stable aggregates using the capillary rewetting and slaking procedures (Gale *et al.*, 2000, Six *et al.*, 2004), but this underestimates the amount of aggregates formed and identifies stable aggregates only as those able to survive slaking.

The maximum and minimum WSSI were theoretical values calculated using methodology similar to that described by (Niewczas and Witkowska-Walczak, 2003) where the maximum WSSI assumes all of the aggregates in a particular size class were 100% stable and the minimum WSSI assumes all the aggregate size classes had a stability of zero except for the smallest aggregate size class which was 100% stable. The experimental WSSI values were then divided by the maximum WSSI values and multiplied by 100 to calculate how close the experimental WSSI values were to the maximum WSSI values.

Soil aggregate stability is a frequently used indicator of soil erodibility. Current methods generally measure only a portion of the soil or use either dry-sieved or wet-sieved aggregates. Our objective was to develop a whole soil stability index (WSSI) by combining data from dry aggregate size distribution and water-stable aggregation along with a 'quality' constant for each aggregate size class. The quality constant was based on the impact of aggregate size on soil quality indicators. Soil quality indicators can be loosely defined as those soil properties and processes that have the greatest sensitivity to changes in soil function. The WSSI was hypothesized to have a better relationship to the impacts of aboveground management than other soil aggregation indices such as a mean weight diameter (MWD), geometric mean diameter (GMD), and the normalized stability index (NSI). Soil samples used in this study were collected from sites established on the same or similar soil types at the Northern Great Plains Research Laboratory in Mandan, ND. By utilizing dry aggregate size distribution, water-stable aggregation, and the quality constant, the WSSI detected differences in soil quality due to management (such as amount of disturbance, plant cover, and crop rotation) with the highest values occurring for the undisturbed, native range and the lowest values for conventional tillage fallowed treatments. The WSSI had the best relationship with management and is recommended as a standard measurement for soil aggregation (Nichols, 2011).

A number of the indices have been proposed for assessing soil stability including mean weight diameter (MWD), geometric mean diameter (GMD), water-stable aggregation (WSA) (Kemper and Rosenau, 1986), aggregate stability index (ASI) (Niewczas and Witkowska-Walczak, 2003), and normalized stability index (NSI) (Six *et al.*, 2004), but these indices either lack a clear differentiation between stable and unstable macro aggregates or apply only to a specific set of aggregate sizes and not the whole (Marquez *et al.*, 2004). These indices also may be biased by procedural factors which may contribute to the artificial decomposition of large aggregates into smaller aggregates by abrasion against the screens or collision of large-sized particles against smaller-sized particles.

Soil structure can be characterized by a variety of methods (Dexter, 1988), and different approaches have been introduced and used to characterize the solid phase of soil structure (Amezket, 1999, Diaz-Zorita *et al.*, 2002, Rohoskova and Valla, 2004). A commonly used method is the wet-sieving type of analysis providing information

on soil aggregate stability and distribution of soil aggregate size fractions (Kemper and Rosenau, 1986, Diaz-Zorita *et al.*, 2002, Nimmo and Perkins, 2002).

2.3 Structural indices in different RCT

Soil structure refers to the size, shape and arrangement of solids and voids, continuity of pores and voids, their capacity to retain and transmit fluids and organic and inorganic substances, and ability to support vigorous root growth and development (Lal, 1991). Favourable soil structure and high aggregate stability are important to improving soil fertility, increasing agronomic productivity, enhancing porosity and decreasing erodibility. The decline in soil structure is increasingly seen as a form of soil degradation (Chan *et al.*, 2003) and is often related to land use and soil/crop management practices. Soil structure influences soil water movement and retention, erosion, crusting, nutrient recycling, root penetration and crop yield. Aggregate stability is used as an indicator of soil structure. Aggregation results from the rearrangement of particles, flocculation and cementation (Duiker *et al.*, 2003). Aggregation is mediated by soil organic carbon (SOC), biota, ionic bridging, clay and carbonates. The SOC acts as a binding agent and as a nucleus in the formation of aggregates. Biota and their organic products contribute to the development of soil structure; which in turn exert a significant control over SOC dynamics. Aggregates occur in a variety of manners and sizes. These are often grouped by size, macro-aggregates ($>250\ \mu\text{m}$) and micro-aggregates ($<250\ \mu\text{m}$) with these groups being further divided by size (Tisdall and Oades, 1982). Different size groups differ in properties such as binding agents and carbon and nitrogen (N) distribution. There are several mechanisms of aggregation. Aggregates are formed in stages, with different bonding mechanisms dominating at each stage (Tisdall and Oades, 1982). Hierarchical theory of aggregation proposes that micro aggregates join together to form macro-aggregates and the bonds within micro-aggregates are stronger than the bonds between macro-aggregates (Edwards and Bremner, 1967). Micro-aggregates ($<250\ \mu\text{m}$) are formed from organic molecules (OM) attached to clay (Cl) and polyvalent cations (P) to form compound particles (Cl-P-OM), which are joined with other particles (Cl-P-OM) to form macro-aggregates $(\text{Cl-P-OM})_x\text{y}$ (Edwards and Bremner, 1967, Tisdall, 1996). Alternatively, macro-aggregates can form around particulate organic matter (POM). As POM is decomposed and microbial exudates are released, the macro-aggregate becomes more stable, the C: N ratio decreases, and micro-aggregates form inside. The internally formed micro-aggregates contain more

recalcitrant SOC pool (Plante and McGill, 2002a, Beare *et al.*, 1994). As the more labile SOC pool is utilized and microbial activity decreases, the supply of exudates decreases and the macro-aggregate loses stability, eventually disrupts and releases more stable micro-aggregates (Jastrow *et al.*, 1998, Six *et al.*, 1999). Plant roots and their rhizosphere have many effects on soil aggregation. Roots enmesh and realign soil particles and release exudates, which result in physical, chemical and biological alterations that influence aggregation. Aggregation tends to increase with increasing root length density, microbial associations, glomalin, and percent cover significantly affect soil aggregate stabilization (Rillig *et al.*, 2002). Aggregate stability is greater in rhizosphere soil than in nonrhizosphere soil (Caravaca *et al.*, 2002) due to rhizo deposition, root mass, root density, size distribution, root turnover, root length, and hyphae growth (Haynes and Beare, 1997). The rhizosphere hosts a large population of micro- and macro-organisms that contribute to SOC and aggregation. Chemically, roots enhance aggregation by releasing a variety of compounds, which have a cementing effect on soil particles. Root mucilage such as polygalacturonic acid may stabilize aggregates by increasing bond strength and decreasing wetting rate (Czarnes *et al.*, 2000).

ZT typically improves soil quality in various dimensions, including soil structure, soil fertility, and soil biological properties (Chauhan *et al.*, 2002, Mohanty *et al.*, 2007). Rice–wheat systems typically have low soil organic carbon (Duxbury *et al.*, 2000). ZT can enhance organic carbon contents in the surface layers and result in higher stability of soil aggregates (Chauhan *et al.*, 2002). Studies have reported that the upper soil surface for ZT was comparatively soft, had higher moisture content and there was no significant difference in bulk density under ZT and CT systems (Yadav *et al.*, 2002a, Kumar *et al.*, 2002b, Malik *et al.*, 2002c). However, such gains during the ZT wheat crop are largely offset by the intensive and anaerobic tillage of the subsequent rice crop (e.g. 5–6 tractor passes including dry plowing, wet plowing and wet planking, irrespective of whether previous crop was ZT or CT wheat (Erenstein *et al.*, 2007b). For enhancement of the structural soil quality the whole cropping system would need to shift to aerobic and ZT conditions with adequate residue management. With the adoption of ZT in rice–wheat systems in the IGP, comparatively less weeds were found in the wheat crop (Malik *et al.*, 1998, 2002c, 2004, Chauhan *et al.*, 2002, Singh *et al.*, 2002a, d, Franke *et al.*, 2007). Soil structure degradation following intensive agricultural activities, soil compaction, loss of structural stability and the

formation of surface crusts give rise to the loss of continuity of elongated transmission pores, which reduces water transport, resulting in increased runoff and soil erosion. One of the most pronounced effects of continuous ZT is the redistribution and stratification of organic matter within the soil profile. Several studies have documented that conservation tillage maintains greater total amounts of organic matter in the soil and improves soil structure. Also, with time, crop yields may increase substantially from what they used to be with more intensive tillage systems (Dick, 1991, Follett and Peterson, 1988, Papendick and Parr, 1997). Although, (Rasmussen and Collins, 1991) stated that appreciable changes in SOC can only be detected in the long-term (20–30 years), Carter (1992) showed on a fine sandy loam soil that ZT and reduced cultivation significantly increased surface SOC in a relatively short time period (3 years or less). Aggregate stability is a soil quality indicator directly related to soil organic matter. The stability of soil surface aggregates relies on soil organic matter, enabling them to withstand rapid wetting and mechanical forces due to tillage implements and vehicular traffic (Tisdall and Oades, 1982, Oades, 1984). Many studies in different soils and climatic conditions, have demonstrated a positive correlation between SOC and structural stability of both macro- and micro-aggregates (<250 μ m) (Cannell and Hawes, 1994).

It was also observed that management practices such as the burial of various crop residues and application of organic fertilizers modify structure (Tejada and Gonzalez, 2005, Atkinson *et al.*, 2009). The sustained addition of crop residue increases the organic carbon content, particularly in the surface layer of soil, which supports the creation of a new soil layer with better and more stable aggregates (Martinez *et al.*, 2008). Crop rotation also affects the percentage. The application of compost and manure improved the soil porosity and the soil aggregation. A better aggregation indicated that the addition of organic materials plays an important role in preventing soil crust formation. The above studies confirmed that adoption of reduced tillage systems is required to prevent soil physical degradation and improve the soil structural quality.

Planting on conventional-tilled beds increases water use efficiency and decreases operational costs compared with conventional tilled wheat without beds (Aquino, 1998, Fahong *et al.*, 2004). Bed planting provides a natural opportunity to reduce soil compaction by confining traffic to the furrows. Next, logical steps to increase their sustainability is to reduce tillage and manage plant residues from the

previous crop on the surface and reshape the beds only as needed between crop cycles. Bed planting also created better soil physical environment all throughout the crop growth, which leads to higher crop productivity (Aggarwal and Goswami, 2003, Sharma and Bhushan, 2001). Limon-Ortega *et al.*, (2006) observed that in a permanent bed wheat-maize planting system after 12 years soil aggregates were greater in size and more stable and the amount of C and N from microbial biomass was more in permanent bed than conventional planting system. Reducing tillage combined with crop residue retention on the soil surface as stubble can increase water infiltration (Bruce *et al.*, 1990, Carter, 1992, Azooz and Arshad, 1996, Elliot and Efetha, 1999, Shaver *et al.*, 2002), reduce soil erosion, increase water use efficiency (Johnston *et al.*, 2002, McGarry, 2002) and reduce water loss by evaporation. Crop rotations, on the other hand, can break soil borne pathogen cycles and reduce weed pressure (Karlen *et al.*, 1994). Diversification of rice-wheat system could be possible with adoption of bed planting, especially by growing vegetables, maize, legumes (chickpea and pigeon pea), oilseeds, cotton, and sugarcane. (Fahong *et al.*, 2004, da Silva and Kay, 1996) demonstrated many advantages of the furrow irrigated raised bed system (FIRBS). One of them was improved water use efficiency by 21–30% combined with an approximate 17% savings in applied irrigation water. Besides, bed planting created better soil physical condition for wheat establishment, growth and development. In addition to this, bed planting made it possible to apply post-emerge nitrogen by band incorporation in the furrow before irrigation as opposed to broadcast, surface application, which improved nitrogen use efficiency by 10–15% which improved grain yields of bed planted wheat through extension of the grain-fill period by providing conditions for a longer, “stay-green” leaf period. Bed-planting system also decreased the humidity in the crop canopy, which helped to reduce disease incidences as well as crop lodging. The above results have thus confirmed that bed planting has emerged as one of promising sustainable soil management technologies). For the future adoptability of bed planting on a large scale, there was a need to study the changes in soil physical environment under bed planting system which could presented in terms of wider or narrower LLWR under bed planting as compared to conventional for showing its effect in improving or deteriorating the soil physical environment. Further, there was a need to correlate LLWR to rooting characteristics and yields of crops.

2.4 Effect of RCT's on soil and water erosion

Dispersion ratio of soils in farmlands was greater than in forests and rangelands. Similarly, (Evrendilek *et al.*, 2004) found that soil erodibility factor was greater in the cropland than in the forest site. Dispersion ratio depends on aggregation of soil particles. Soils in rangelands and forests are generally considered to have higher structural stability than soils in farmlands for soils in farmlands are cultivated continuously (Karagul, 1999). Soils in all land use types were found to be sensitive to erosion.

Colloid-moisture equivalent ratios of soils in farmlands, rangelands and forestlands were found to be 0.87, 1.08 and 0.74 respectively. According to statistical results, there was significant difference between colloid moisture equivalent ratio of soils in rangelands and in forestlands (Selma Yasar Korkanc, 2008).

Erosion ratio of soils in farmlands, rangelands and forests was found to be 37, 31 and 31 respectively. Soils did not show significant differences for different land use types. Different land uses are associated with different soil conditions: loss of ignition, soil skeleton percentage, <2 mm fraction ratio, root ratio and pH show significant difference according to land use types. In farmlands, low values of loss of ignition and high values of >5 mm. fractions and pH compared with the other land use types is important for evaluating land degradation. It was determined that sand and clay proportion must be considered as significant indicators for erodibility evaluations in the research area. According to evaluation made for three erodibility indices, it was found that soils of the study area are susceptible to erosion. As to erodibility indices generally farmland soils were the most sensitive ones to erosion. Soil tillage generally breaks the soil aggregates. For this reason, the action of converting forestlands into farmlands and rangelands should be prevented (Selma Yasar Korkanc, 2008).

Bryan, (2000) observed that many components of erosional response, such as partitioning between rill and interrill or surface and subsurface processes, threshold hydraulic conditions for rill incision, rill network configuration and hill slope sediment delivery, are strongly affected by spatially variable and temporally dynamic soil properties. This agrees with other recent studies, but contrasts markedly with long-held concepts of soil erodibility as an essentially constant property for any soil type. Properties that determine erodibility, such as soil aggregation and shear strength, are strongly affected by climatic factors such as rainfall distribution and frost action, and show systematic seasonal variation. They can also change significantly over much

shorter time scales with subtle variations in soil water conditions, organic composition, microbiological activity, age-hardening and the structural effect of applied stresses. Property changes between and during rainstorms can dramatically affect the incidence and intensity of rill and interrill erosion and, therefore, both short and long-term hill slope erosional response. Similar property changes, linked to climatic conditions, may also significantly influence the stability and resilience of plant species and vegetation systems. Full understanding of such changes is essential if current event-based soil erosion models such as WEPP and EUROSEM are to attain their full potential predictive precision.

Adoption of Green Revolution (GR) technologies, incorporating the use of high-yielding varieties, fertilizers and irrigation, led to increased production and productivity of both these crops. However, continued intensive use of GR technologies in recent years has resulted in lower marginal returns and, in some locations to salinization, overexploitation of groundwater, physical and chemical deterioration of the soil, and pest problems. Field results show that the resource conserving technologies, and component of conservation agriculture, improve yields, reduce water consumption, and reduce negative impacts on the environmental quality. As Conservation tillage maintains crop residues on the surface, it brings about structural improvement, increases the air capacity, may cause the roots to extend into and exploit a larger volume of soil in addition to increasing water retention in the soil profile (Sarkar *et al.*, 2003; Pernes-Debuyser and Tessier, 2004). It may increase the overall moisture availability to the crop (Dexter, 1988, Ekwue, 1992, El-Shakweer *et al.*, 1998). Several studies have documented that conservation tillage maintains greater total amounts of organic matter in the soil and improves soil structure; also, with time, crop yields may increase substantially from what they used to be with more intensive tillage systems. No-till, reduced tillage and stubble retention systems have been found to result in equivalent or even a higher crop yield compared to conventional tillage over a wide range of environment conditions. The influence of different tillage systems on the yield of different crops, corn (*Zea mays* L.) (Hashemi-Dezfuli and Herbert, 1996, Beyaert *et al.*, 2002), soya bean (*Glycine max* L.) barley (*H. vulgare* L.), oats (*Avena sativa* L) and wheat (*T. aestivum* L.) (Comia *et al.*, 1994) have been studied. However, tillage systems are location specific, their success depends on soil, climate and local management practices. Crop residues accumulating on the soil surface form a barrier to water loss by evaporation, decrease soil

temperatures. More stable soil aggregate structure is present under zero tillage (ZT), compared to conventional tillage (CT) (Carter, 1992, Elliot and Efetha, 1999, Limon-Ortega *et al.*, 2002). Yield benefits from conservational Agriculture (CA) are mainly linked to its positive environmental and soil effects compared with CT. Examples are reduced erosion and fewer surfaces crusting, increased aggregate distribution and stability and increased infiltration and water content of soil (Govaerts *et al.*, 2009a, Hobbs *et al.*, 2008). Improved timeliness of seeding also increases yields (Hobbs *et al.*, 2008). Along these lines, CA has increased crop yields compared with CT in many countries including USA, Australia, Mexico, Canada and Brazil (Dick *et al.*, 1991, Govaerts *et al.*, 2005, Malhi and Lemke, 2007).

Resource-conserving technologies (RCTs) such as zero-tillage (ZT) and bed planting have been shown to be beneficial in terms of improving soil health, water use, crop productivity and farmer's income (Gupta and Sayre, 2007, Gupta and Seth, 2007). ZT is widely adopted by farmers in the North-western IGP of India, particularly in areas where rice is harvested late. However, to get the full benefits of ZT, both rice and wheat need to be grown with a 'double zero-tillage' system (Jat *et al.*, 2009, Bhushan *et al.*, 2007).

For computing the potential productivity loss due to soil erosion (Neill, 2003), soil quality was presented in terms of Productivity index (PRI). The PRI model rated soils on the sufficiency for root growth based on potential available water storage capacity, bulk density, aeration, pH, and electrical conductivity. Physical rating index (PI) by Gupta and Abrol (1993) was also another index used in soil physical constraint analysis for assessing the production potential of soils. It was one step beyond land capability classification. Efficiency of any suggested management practice for alleviating these constraints could be assessed in terms of changes in its rating value and hence its production potential (Aggarwal and Choudhury, 2005).

Soil structure is a complex soil property, partly related to inherent characteristics of particle size and clay mineralogy and partly to anthropogenic influences related to land use and management. According to (Kay and Angers, 2001), soil structure can be described in terms of: (i) structural form; the heterogeneous arrangement of pores and solids at any given time; (ii) structural stability, the ability of soil to retain its structural form after exposure to stress and (iii) structural resilience: the ability of soil to recover its structural form through natural processes. Soil structural form may be described visually in terms of the size, shape

and porosity of individual units of structure (aggregates) to which additional physical properties such as strength and stability can be added. However, from such a description, it may be difficult to derive an indication of the quality of the structure for agricultural production.

Hence, in past many indices of structure were developed, based on laboratory tests for stability of individual aggregates, their dispersion in water or pore size distribution or on field permeability assessments, for example those of (Low, 1954, Williams and Cooke, 1961 and Currie, 1965). Aspects of soil structure are commonly described and quantified from water retention, water and gas permeability, gas diffusivity and aggregate stability (De Boodt *et al.*, 1967, Kay and Angers, 2001). More recent methods involve micromorphology (Ringrose-Voase, 1991), 3D visualization and advanced modeling (Young and Crawford, 2004).

Knowledge of the structural stability of soils is important in evaluating the crusting/sealing potential of soils, soil permeability, steady-state infiltration rates, soil erosion and seedling emergence and in predicting the capacity of soils to sustain long-term crop production. Due to heavy mechanization in agriculture in recent past, work on land leveling and large scale adoption of zero tillage and bed planting is visible in alluvial plains of Haryana. Hence, there is a need for computing soil erodibility indices in farmer's fields where such technologies are being practiced from past several years for monitoring the impact of these RCT's on soil structural stability, overall soil physical health and productivity of land. Thus the current study was conducted with the objective to find out correlation between crop productivity and soil structural indices for suggesting the most appropriate conservation tillage practice in the surveyed sites.

3. MATERIAL AND METHODS

3.1 Study Area

The present study was conducted in Rai block of Sonapat district in Haryana located at $28^{\circ}48'15''$ to $29^{\circ}17'10''$ north latitude and $76^{\circ}28'40''$ to $77^{\circ}12'45''$ east longitude and at an altitude of 228 m above mean sea level. Rai block in Sonapat district is part of the Eastern Haryana plain (Trans Indo-Gangetic Alluvial plains). On its eastern boundary, Yamuna River flows and on its western boundary, Delhi branch of western Yamuna canal is present. It has gradual slope towards south in which direction Yamuna flows. Trees and shrubs growing in the district include Akk or Badar, Shisham, Babul, Lasura, Aam, Jamun, jand, Karir, Pipli etc. and are found widely. The main field crops grown in this area are Rice, Wheat, Maize, Sugarcane, Sorghum etc. (Figure 3.1)

3.2 Climate

The climate of the district is characterized by the dryness of the air with an intensely hot summer and a cold winter. The cold season starts by late November and extends to about the middle of March. It is followed by hot season, which continues to about the end of June when the southwest monsoon arrives over the district. The period from July to September is the southwest monsoon season. The block has a sub-tropical Continental Monsoon climate where we find seasonal rhythm, hot summer, cool winter, unreliable rainfall and great variation in temperature. Rainfall distribution is relatively satisfactory in relation to the western parts of Haryana and it is mainly concentrated during Monsoon. Air is dry during greater part of the year. Sometimes dense fog occurs in winter season.

The mean annual rainfall of the district is 624 mm, 76% of the annual rainfall is received during the southwest monsoon from July-September and the rest is received through 'Western Disturbances' from December to February. Air remains dry during most of the part of the year. July is the wettest month of the year with 7.5 rainy days and 169 mm rainfall. January is the coldest month with mean daily maximum temperature 21.3°C and mean daily minimum temp 7.3°C . May is the hottest month with mean daily maximum temp 26.6°C . In May and June, the maximum temperature sometimes reaches about 47°C . The mean wind velocity varies from 3.5 km hr^{-1} during October to 4.3 km hr^{-1} in April.

3.3 Soils

The soil of the study area belongs to the major group of Indo-Gangetic alluvium. The soil texture is mainly sandy loam, sandy clay and sandy clay loam soil. The soils belong to order Entisol, suborder fluvents, great group ustifluvents.

Soil samples were collected from villages where both resource conservation technologies (RCT's) *i.e.* bed planting and zero were being adopted by most of the medium and big farmers for more than 6-7 years.

Villages selected for taking soil samples in farmers fields practicing bed planting were Badkhalsa, Bahalgarh, Chauhanjoshi, Hasmabad, JatJoshi, Khewra, Lawanspur, Rathwanda, ParliKalan, Parlikhurd, Mirakpur and Nathupur. Out of 12 selected villages, soil samples were collected in August-September, 2011 (*kharif* season) in 6 villages where Tomato, brinjal, chilli, Pumpkin, Okra and carrot were grown on beds in fields and in other six villages soil observations were taken in February, 2012 where farmers were growing Cabbage, cauliflower, radish, Dhania, French bean and Beet leaf on beds. In each of the above mentioned village, for comparing bed planting system with conventional system, three soil samples were taken from 0-15 and 15-30 cm soil layers under vegetable planted beds and simultaneously another three samples from three nearby fields where Sorghum in *Kharif* and wheat in *rabi* were sown on flat lands after conventionally tilling (2 times harrow+2 times tiller followed by pata).

Soil samples (in triplicate) were also taken from 0-15 and 15-30 cm in the first week of January in farmer's fields where wheat was sown by zero seed drill in mid November. These villages were Jakoli, Khurrampur, Manoli, Nasirpur, Pabsara and Pritampur. Simultaneously, soil samples (again in triplicate) were also collected from nearby conventionally tilled wheat fields to compare soil properties under zero tilled wheat with those under conventionally tilled wheat. Since none of the farmers in that area practiced direct sowing of rice without tillage, no observation could be recorded to compare zero tilled rice with conventionally puddled (wet tilled) rice.

Summary of the treatments studied:

Conventional versus bed system

CTJ- CTW	Conventionally tilled Jowar in <i>kharif</i> followed by conventional tilled wheat
Veg. on bed-veg. on beds	vegetables on beds in both <i>kharif</i> and <i>rabi</i> season

The bed planter used by farmers for making beds was called ‘Trifala’ in local language and was used for growing vegetables both in *kharif* and *rabi* seasons (Figure 3.2).

Conventional versus Zero tillage system (Figure 3.3)

Treatment Name	Specification
CTR – CTW	Puddled rice followed by conventional tilled wheat
DR /ZR- ZT	Direct seeded rice followed by zero till wheat

3.4 Soil properties studied

Soil samples were taken by core auger for determination of soil properties such as pH, electrical conductivity (EC) bulk density (BD) , soil texture (by dispersing with water and also by completely dispersing it by using hexametaphosphate), soil organic carbon, saturated hydraulic conductivity (K_s), soil water contents at saturation, field capacity and wilting point. Besides field saturated hydraulic conductivity (K_{fs}) was determined in situ by using Guelph permeameter.

3.4.1 Soil bulk density

Soil bulk density (BD) was determined by using core auger method. For this purpose, a core cutter of 5.5 cm diameter and 15 cm height was used. Core cutter held an assembly of a sectional cylinder (core) of 6 cm diameter and 6cm height with 2 rings of same diameter but 2 cm height on either side of it and was screwed to the collar of sampler (2.5 cm high) from the upper side. Collar of the cutter was attached to a galvanized thick hollow iron rod of nearly 85 cm height. The other end of the rod was attached to a handle. The bottom part of the cutter had a sharp edge and nearly 2.5 cm of the bottom portion of core cutter was slightly bent inward, hence the inner assembly remained above 2.5 cm from bottom part of cutter. For taking samples, the assembled core cutter was positioned over the sampling site and pressed inside the soil by rotating the handles or by dropping a hammer over the center portion of the upper end of the thick rod until the edge of the collar came to rest over the soil surface. Core cutter was then moved back and forth to loosen the soil grip around it. It was then slowly pulled out of the hole. After unscrewing the cutter from the collar, the unit of sectional cylinder with rings on each side was taken out carefully. Rings with undisturbed soil were used in pressure plate and determination of maximum

water holding capacity. Cores with field soil were dried to 105°C in the oven and weighed. Bulk density (g cm^{-3}) of soil was calculated from the formula:

$$BD = \frac{(X - Y)}{V}$$

Where X = Weight of core with oven dry soil (g)

Y = Weight of core (g)

V = Volume of core (cm^3).

3.4.2 Aggregate stability

The stability of the aggregates was measured on air dried soil samples using the ‘dry and wet sieving’ method of De Leenheer and De Boodt (1959), adjusted by Hofman (1973) as described by Leroy *et al.*, (2008). The instability index was calculated as the difference of the mean weight diameter (MWD) of the dry sieving minus the MWD of the wet sieving. The inverse of the instability index, *i.e.* the stability index (SI), was taken as a measure of the stability of the aggregates (De Leenheer and De Boodt, 1959, De Boodt and De Leenheer, 1967). Soil water stable aggregates from wet sieving contribute more to the stability of soil structure, and are much more important than unstable aggregates. MWD and GMD are two common indicators for characterizing size distribution of soil aggregates. The higher the values of MWD and GMD are, the higher the degree of aggregation and the stronger the stability is (Nimmo and Perkins, 2002).

3.4.2.1 Dry aggregate stability (Chepil, 1962):

To determine dry aggregate stability, large clods (>20 mm) of air-dried samples were broken into smaller fragments along their natural planes of weakness by using gentle manual forces. A 50 g soil aggregates passed through 8mm sieve and retained on 5 mm sieve were put on the top of a nest of sieves of decreasing mesh sizes 5, 2, 1, 0.5 and 0.25 mm clamped on a stand of a dry sieve shaker (Figure 3.4). The sieve shaker is driven by a ¼ HP geared motor. The sieve table is inclined from the vertical axis and the direction of inclination changes progressively in the clockwise direction. In addition to gyratory motion of table, there is a tapping motion as well. It was operated on 220 volt, 50 HZ, AC supply. After shaking these sieve for 5 minutes, soil retained on each sieve was collected to obtain the dry weight of six aggregate size fractions: <0.25; 0.25–0.5; 0.5–1; 1–2; 2–5 and >5 mm. Weights of

these aggregates remaining on each sieve were used to compute dry sieving mean weight diameter (DS-MWD).

$$DS-MWD = \sum x_i w_i$$

Where w_i is the weight of each aggregate class i in relation to the weight of soil sample taken for analysis, x_i the mean diameter of the class (mm).

3.4.2.2 Wet aggregate stability (Yoder, 1936).

To determine wet aggregate stability, samples were prepared in a manner similar to that for dry aggregate stability determination as mentioned above. 50g of prepared samples was moistened after transferring it to the top sieve of nest of the sieves (5, 2, 1, 0.5 and 0.25) mm clamped on a stand attached to a wet sieve shaker. The wet sieve shaker was made to move the nest of sieves up and down in a water filled drum with a frequency of 30-35 cycles per minute and a stroke of 3.8 cm for 5 minutes. After shaking these sieve for 5 minutes, soil retained each sieve was collected to obtain six water stable aggregate size fractions: <0.25; 0.25–0.5; 0.5–1; 1–2; 2–5 and >5 mm. Weights of the aggregates remaining on each sieve were used to compute wet sieving mean weight diameter (WS-MWD).

$$WS-MWD = \sum x_i w_i$$

Where w_i is the oven dry weight of each aggregate class i in relation to the oven dry weight of soil sample taken for analysis, x_i the mean diameter of the class (mm).

3.4.3 Saturated hydraulic conductivity (K_s)

The constant-head test with the permeameter is one of the most commonly used methods for determining the saturated hydraulic conductivity of soils in the laboratory. The samples were taken in cores at maturity of crop with the help of core auger. This procedure allows water to move through the soil under a steady state head condition while the quantity (volume) of water flowing through the soil specimen is measured over a period of time. The test operates in accordance with the direct application of Darcy's law to a soil liquid configuration representing a one-dimensional, steady flow of a percolating liquid through a saturated column of soil from a uniform cross-sectional area. In this method, a cylindrical soil sample of cross-sectional area A and length L is placed between two porous plates that do not provide any extra hydraulic resistance to the flow. A constant head difference, $H_2 - H_1$, is then applied across the test sample. By measuring the volume V of the test fluid that flows

through the system during time t , the saturated hydraulic conductivity K_s of the soil can be determined directly from Darcy's equation:

$$K_s = \frac{VL}{At(H_2 - H_1)}$$

Where; K_s = Saturated hydraulic conductivity (cm day^{-1})

A = Cross sectional area of the core

t = Time of water flow

$H_2 - H_1$ = Hydraulic head difference

V = Volume of water flow during t

L = length of the core

3.4.4 Field saturated hydraulic conductivity (K_{fs})

Saturated Hydraulic Conductivity in field was measured by Guelph permeameter which is a constant head well permeameter (Reynolds, 1991, Reynolds *et al.*, 2002) consisting of a mariotte bottle that maintains a constant water level inside a hole augered in the soil. The method involves measuring the steady-state rate of water recharge into the soil from a cylindrical well hole, in which a constant depth (head) of water is maintained. The analysis of steady-state discharge from a cylindrical well in unsaturated soil, as measured by the Guelph Permeameter technique, accounted for all the forces that contribute to three dimensional flow of water into soils: the hydraulic push of water into soil, the gravitational pull of liquid out through the bottom of the well, and the capillary “pull” of water out of the well into the surrounding soil.

Equation for one-head analysis for K_{fs} :

$$K_{fs} = \left[\frac{CQ}{2\pi H^2 + \pi a^2 C + 2\pi H/\alpha} \right]$$

Where;

K_{fs} - Field-saturated hydraulic conductivity (entrapped air present), in cm/sec .

R - Steady state rate of fall of water in the reservoir tube of the permeameter, in cm/sec .

Alpha parameter (α) - slope of the natural log of K - Q curve = 0.12 cm^{-1} for most of agricultural soils, H - Well height in cm , a - Well radius, in cm ,

$Q = XR$, where X - reservoir constant = 35.43 cm^2

C -Factor - a numerically derived shape factor, dependent on the well radius and head H of water in the well.

3.4.5 Soil texture

International pipette method (Kilmer and Alexander, 1949) was used to determine sand, silt and clay percentage for each sample. USDA textural triangle was used to determine textural classes.

3.4.6 Measurement of Moisture content at Field capacity and Wilting point using Pressure Plate apparatus.

Pressure plate apparatus (Soil Moisture Equipment Corporation, USA) method was used for obtaining soil water retention curve. It consists of a pressure chamber in which saturated soil samples (disturbed or undisturbed) are placed on porous ceramic plate through which the soil solution or air can pass easily but not the soil particles. As soon as the air pressure inside the chambers is raised above the atmospheric pressure, excess water is released until the equilibrium is attained. At this point moisture content of soils is measured gravimetrically which refers to the moisture content at the applied pressure.

Water retention by undisturbed soil core samples at 0.33 (FC) and 15 bar (PWP) were determined. The pressure plates were saturated for overnight and undisturbed soil samples (cores) were placed on plate. Then water was added to saturate the sample and kept for 24 h for complete saturation. Saturated plates containing soil samples were placed in pressure chambers and desired pressures were applied. For attaining equilibrium it was kept for 48 h at the specified pressure. Then, samples were taken out from the chambers after they reached to equilibrium and the weights of soils were recorded. Following oven-drying at 105-110°C till constant weight was attained, the dry soils were recorded. The moisture content retained by each sample at specified potential was determined from the moist and dry weight as recorded.

3.4.7 Non capillary porosity and available water content

Non capillary porosity and available water retention capacity were determined by following formulae:

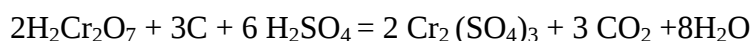
Non capillary porosity (%) = $\theta_{\text{SAT}}(\%) - \theta_{\text{FC}}(\%)$, and

Available water retention capacity (AWRC) = $\theta_{\text{FC}}(\%) - \theta_{\text{PWP}}(\%)$

3.4.8 Soil organic carbon (OC)

Soil organic carbon for each soil sample was measured by Walkley and Black (1934) method. In this method organic matter is oxidized with chromic acid (potassium dichromate + H₂SO₄) and the unconsumed potassium dichromate is back

titrated against ferrous sulphate or ferrous ammonium sulphate (redox titration). Carbon in the sample is oxidized as follows:



Thus, $2\text{H}_2\text{Cr}_2\text{O}_7$ or $2\text{K}_2\text{Cr}_2\text{O}_7 = 3\text{C}$

Or 588 g of $\text{K}_2\text{Cr}_2\text{O}_7 = 36$ g of C

Or 12 liters of 1 N $\text{K}_2\text{Cr}_2\text{O}_7 = 36$ g of C

Or 1 ml of 1 N $\text{K}_2\text{Cr}_2\text{O}_7 = 0.003$ g of C

3.4.8.1 Reagents:

- 1 N Potassium Dichromate: 49.04 gm of AR grade $\text{K}_2\text{Cr}_2\text{O}_7$ was dissolved in 500 ml of distilled water and the volume was made to one liter.
- Conc. Sulphuric acid
- 0.5 N Ferrous ammonium sulphate: 196 gm of ferrous ammonium sulphate was dissolved in distilled water, 20 ml of conc. H_2SO_4 was added to it and the volume was made to one liter. The ferrous ammonium sulphate should be from a fresh lot and the light green color in color. Yellowing of the salt indicates its oxidation.
- Diphenylamine indicator: 0.5 gm of the dye was dissolved in a mixture of 20 ml of distilled water and 100 ml of conc. H_2SO_4
- Orthophosphoric acid (85%), or sodium fluoride

3.4.8.2 Procedure: 1 gm of 0.2 mm soil sample was weighed into 500 ml conical flask. 10 ml of 1 N $\text{K}_2\text{Cr}_2\text{O}_7$ and 20 ml of conc. H_2SO_4 were added to the flask. The flask was swirled a little and was kept on an asbestos sheet for 30 minutes. 200 ml of distilled water and 10 ml of orthophosphoric acid were added to the flask. 1 ml of diphenylamine indicator was added to the flask. 0.5 N ferrous ammonium sulphate was taken in 50 ml burette and the sample was titrated until the green started appearing. When the titrate value was <6 , the experiment was repeated taking 0.2 to 0.5 g of soil sample. Use of NaF along with H_3PO_4 gives a sharper end point. High

chloride content, as in case of saline soils, interferes in the estimation. It can be prevented by adding Ag_2SO_4 @ 1.25 per cent to the conc. Sulphuric acid

$$\text{Organic carbon (\%)} \text{ in soil} = \frac{10 (B - S)}{B} * 0.003 * \frac{100}{\text{wt. of sample (g)}}$$

where B and S stand for the titrate values (ml) of blank and sample, respectively

3.5 Methodology (Statistical and Geostatistical methods)

3.5.1 Statistical analysis:

Descriptive statistical analysis was carried out for K_{fs} , BD, θ_{PWP} , θ_{FC} , θ_{SAT} , AWRC, OC %, sand %, silt % and clay %, DR, DS- MWD, WS- MWD, CMER, ER, and CR.

3.5.2 Multiple regression analysis

A stepwise multiple regression equations (Pedotransfer functions) were developed for predicting some dependent variables such as, AWRC, DR, DS-MWD, WS-MWD, CMER, ER, CR as a function of OC %, clay %, silt % and sand %, K_{fs} and NCP using “Statistica Pro-2008 ” software package. Since the degree of freedom (df) was large, t value at 5% level of significance if found >2 , was an indication that independent parameter had significant effect on dependent variables, or other way if p value of parameter was <0.05 , then also the parameter was considered to have significant effect on dependent variables.

3.5.3 Computation of various soil structural stability indices

Calculation of few structural/erodibility indices required determination of calgon (Na hexametaphosphate) dispersed and water dispersed silt+clay. The other important parameter required for computation of few indices was moisture equivalent which was considered equal to soil water content at field capacity. The different erodibility indices calculated were Dispersion ratio, Erosion ratio, Clay moisture equivalent ratio, Clay ratio and Stability index.

1. Dispersion ratio (Middleton, 1930) = % water dispersible (silt+clay)/% calgon dispersible (silt+clay)
2. Erosion ratio (Middleton, 1930) = dispersion ratio/clay moisture equivalent ratio

3. Clay moisture equivalent ratio = % clay / % moisture equivalent
4. Clay ratio = % (sand + silt) / % clay
5. Stability Index = $S_b - S_a$

S_b = % calgon dispersible (silt + clay)

S_a = % water dispersible (silt + clay)

3.5.4 Productivity rating indices:

The productivity index (PI) model was developed to evaluate soil productivity in the top 100 cm, especially with reference to potential productivity loss due to soil erosion (Neill, 1979). The PI model rates soils on the sufficiency for root growth based on potential available water storage capacity, bulk density, aeration, pH and electrical conductivity. A value from zero to one is assigned to each property describing the importance of that parameter for root development. The product of these five index values is used to describe the fractional sufficiency of any soil layer for root development.

Physical rating index by Gupta (1986) was one such tool for constraint analysis and was used for assessing the production potential of soils. Physical rating of soils for agricultural land was one step ahead. In this method, in addition to basic physical parameters, few more dynamic parameters such as bulk density, infiltration rate, soil organic matter, water table depth and available water storage capacity were used for physical constraint identification along with the estimation of relative magnitude of their severity. Accordingly, the production potential of these soils could be predicted under optimum levels of water and fertilizer inputs along with the adoption of appropriate plant protection measures (Gupta and Abrol, 1993). Efficiency of any suggested management practice for alleviating these constraints could be assessed in terms of changes in its rating value and hence its production potential.

As the concept of precision farming is gaining importance, there is a need for presenting a procedure for assessment of soil physical health of the farm and correlating it with the crop yield. For this purpose prediction maps of the important physical properties along with their ratings should be prepared by appropriate interpolation technique. The overall soil physical health should be quantified in terms of a unified soil physical health index prepared from the individual rating values of the important soil physical parameters.

Hence an attempt was made in this paper to assess and map the spatial variation of soil physical health of agriculture farm and to examine correlation between spatial variation of soil physical health and yield of crop in the farm.

3.5.5 Methodology for computing soil physical health index (PI):

For a given site, each of these parameters was assigned a rating value corresponding to its actual value by referring to rating chart (Gupta, 1986). Each of this parameter was given a score of 1 if the parameter value lies within the optimum range. If the value lies below or above the critical limit, a score less than 1 were given. Greater the deviation of parameter value from optimum range, lesser the score given to it. The product of rating values of all the eight parameters gave the physical rating index. PI was an indicator of overall soil physical health status. For range of PI >0.75 , $0.50-0.75$, $0.25-0.50$ and <0.25 , soil physical health status and accordingly its production potential could be labeled as very good, good, medium or poor, respectively.

As per physical rating methodology suggested by Gupta (1986), same ranges of soil parameters were assigned different rating values under rice and wheat cultivations because optimum soil physical environment required for their growth were different.

3.5.6 Preparation of prediction maps:

Maps for the study area were prepared using geo-processing tools of Arc GIS software. To prepare prediction maps, firstly three vector shape files- one point file (for preparing data attribute table), one line file (for showing roads and canal) and two polygon files (for showing block boundary and village boundaries) were created in Arc Catalogue and were added to a new Arc Map. In next step, scanned map of Rai block was geo referenced in Arc Map. After that, vector files were digitizing for Rai block *i.e.* block boundary, 25 village boundaries, roads, rivers and canals. Sampled data points, collected using GPS with latitude and longitude for each location, were digitized and added in the map as an attribute table. All the measured and computed soil properties and indices were added as separate fields in this attribute table and prediction maps (smooth 2D-surfaces) of each property was generated using most widely used interpolation technique-inverse distance weighting method (IDW) (Franke, 1982). Prediction maps are actually filled contour maps showing different ranges of the given parameter with different colours. Values of BD, AWC, K_{fs} , OC and NCP were divided into ranges similar to those given in physical rating method

and appropriate rating values were assigned to them. Physical rating index (PI) at each sampling point was determined by multiplying the rating values for all five parameters. Reason for multiplication of individual rating values for defining the PI was that this index was an indicator of soil productivity. Large deviation in any of the individual parameter value from its optimum range could bring down the yield drastically and such a response could only be observed if the rating values of individual parameters were multiplied. Lastly, these soil maps were subjected to raster map calculations (based on arithmetic, boolean and relational operators) to compute percentage of total area under different ranges.

4. RESEARCH PAPER-1

To compute soil structural indices under different resource conservation technologies

4.1 Abstract

A study was conducted in farmers' fields of Rai block of Sonapat district to study the long term impact of two widely adopted resource conservation technologies (RCT's) namely bed planting and zero tillage on structural properties of soils of recent alluvial plains of river Yamuna. Vegetables growing bed planted areas mostly had medium texture soils, easy access to market and availability of fresh water. Zero tillage was practiced mainly by farmers to timely sow wheat in fine textured soils and low lying areas where soils do not dry even in mid-November.

Aggregate mean weight diameter by dry sieving and wet sieving (DS-MWD and WS-MWD) under different RCT's were studied to compare structural condition of the soils under continuous use of these technologies. Other important structural indices such as dispersion ratio (a measure of ease of dispersion) (DR), colloid moisture equivalent ration (a measure of ease of percolation) (CMER), erosion ratio (EI), stability index (SI), clay ratio (CR) were also studied to monitor the susceptibility of soil to erosion.

Results revealed that in the surveyed villages under conventional tillage, the average magnitude of DR and ER were 0.58 and 0.82, respectively, and CMER was <1, which indicated the erodible nature of these soils. Analysis of data of bed and conventional systems revealed that on an average, there was 0.07-0.08% increase in OC in bed planted system as compared to conventional system. It was mainly due to fewer disturbances in soil because of reshaping of beds for next two seasons before making fresh beds. Improved soil OC in bed system increased WS-MWD (1.89 mm) as compared to CT (1.57 mm). On the other hand, DS-MWD of bed system was lower than that of CT. Therefore CMWD was lower in beds as compared to CT, which indicated improvement in aggregate stability by adoption of bed planting system. The decrease of DR, ER and CR from 0.66, 0.52 and 4.25 under CT to 0.42, 0.28 and 2.38 under beds indicated reduced eroding tendency of these soils under bed planting. Similarly increase in CMER and SI from 0.75 and 20.2 under CT to 1.1 and 34 under bed also indicated improvement in soil structural condition by bed planting. Comparison of soil data of ZT and CT showed improvement in OC, AWC and

reduction in BD and PR under ZT as compared to CT. Improved soil OC in ZT increased WS-MWD (mm) as compared to CT (mm). The decrease of DR, ER and CR from 0.74, 0.63 and 5.99 under CT to 0.6, 0.46 and 3.8 under ZT indicated improved aggregation under zero tillage. Similarly increase in CMER and SI from 0.66 and 9.21 under CT to 0.7 and 20.4 under ZT also indicated improved soil structural condition by adoption of zero tillage. Thus in nutshell it was concluded that by adopting suitable RCT's soil carbon and aggregation were improved and soils became more resistant to erosion.

4.2 Introduction:

Intensive cultivation of agricultural soils can lead to deterioration in soil structure and other soil physical properties and consequently reduction in crop productivity. Thus the need for tillage has been questioned in the last few decades because of the excessive erosion from farmland after tillage. At the same time, it is known that inappropriate use of applied inputs and overexploitation of natural resource base, principally land and water, in many situations in past had led to secondary salinization in low-quality aquifer zones, groundwater table recession in fresh water aquifer zones, physical and chemical deterioration of the soil and water quality due to nutrient mining and pollution of ground water in some locations due to over application of nitrogenous fertilizers and of environment through crop residue burning and pesticide use (Pingali and Shah, 2001, Gupta *et al.*, 2003).

Rice–wheat systems of the eastern IGP have remained largely labor intensive and less mechanized. Farmers use low inputs because of socio-economic constraints and serious problems of drainage congestion and rainwater management.

In the IGP, new resource conserving technologies for proper land and water management are being developed for enhancing crop productivity. Resource-conserving technologies are defined here as any practice that improves the efficiency of use of natural resources, including water, air, fossil fuels, soils, inputs, and people. Adoption of the resource conserving technologies offers newer opportunities of better livelihood for the resource poor small and marginal farmers. At the same time, these technologies are generating alternative sources of productivity growth through diversification and intensification of production systems.

Experiences from Pakistan (Punjab, Sindh and Baluchistan provinces) showed that with zero-tillage technology farmers were able to save on land preparation costs by about Rs. 2500 per ha and reduce diesel consumption by 50 to 60 liters per ha.

Zero tillage allowed timely sowing of wheat, enabled uniform drilling of seed, improved fertilizers use efficiency, saved water and increased crop yields up to 20 percent. The number of zero tillage drills for timely sowing of wheat in saline alkali patches and fine textured soils of Haryana and Punjab has increased tremendously in past few years. Farmers have also adopted bed planting of vegetables. Bed and furrow planting of cotton is finding favour with the farmers due to savings in irrigation water and related benefits of improved use-efficiency of applied fertilizers, reduced soil crusting, etc. Many farmers are now practicing intercropping in raised bed system. In this system wheat is planted on the raised beds and mint or sugarcane in the furrows. Inter-cropping systems such as maize+potato/onion/redbeets or sugarcane+chickpea/Indian-mustard are also becoming popular with farmers in western Uttar Pradesh, India. There is widespread use of laser land leveler which helps in curtailing irrigation, reduces labour requirement, enhances cultivated area and improves overall productivity.

Now the main issue is regarding the selection of appropriate resource conservation technology for a given soil type, climatic condition and crop. Since not much work has been done on development of RCT's for different regions of IGP. There is a need to evaluate the impact of these technologies on crop productivity and also on soil quality specially soil structural condition. Unstable soil structural conditions created by a given soil management practice may lead to soil and water erosion in the form of increase sediment yield and runoff. Most of Runoff from agricultural land may carry sediments, chemical fertilizers and pesticides, all of which can degrade water quality and upset the ecosystems of streams, lakes, reservoirs, and rivers. Research in this area frequently recommends the adoption of reduced tillage practices to prevent soil structural degradation, soil losses by erosion and to reduce consequent environmental impacts. However, there are also some soil types that are unsuitable for minimum tillage. In order to evaluate the impact of management practices on the soil environment it was necessary to quantify the modifications to soil structure by these practices. A number of the indices had been proposed for assessing soil stability including mean weight diameter (MWD), geometric mean diameter (GMD), water-stable aggregation (WSA) (Kemper and Rosenau, 1986), aggregate stability index (ASI), Erosion index, dispersion ratio etc.

In literature very little work has been reported showing the long term effect of different soil management practices on soil structural stability presented in terms of

aggregate stability indices. Hence the present study was conducted in farmers fields under different blocks of Sonapat district of Haryana (part of trans-Indogangetic plain) where such conservation technologies are being practiced from past several years and measurement of important and relevant soil physical properties will be carried out for computing soil structural indices under different resource conservation technologies. Appropriate sustainable, ecofriendly and economically viable conservation technologies for different agricultural lands will be suggested on the basis of their merit in terms of increase in soil structural stability along with better soil physical health and productivity of different cropping system on sustainable basis. Hence, the objectives of the proposed study were to compute soil structural indices under different resource conservation technologies.

4.3 Materials and Methods:

4.3.1 Study Area

The present study was conducted in Rai block (figure1) of Sonapat district in Haryana located at $28^{\circ}48'15''$ to $29^{\circ}17'10''$ north latitude and $76^{\circ}28'40''$ to $77^{\circ}12'45''$ east longitude and at an altitude of 228 m above mean sea level. Rai block in Sonapat district is part of the Eastern Haryana plain (Trans Indo-Gangetic Alluvial plains). On its eastern boundary, Yamuna River flows and on its western boundary, Delhi branch of western Yamuna canal is present. It has gradual slope towards south in which direction Yamuna flows. Trees and shrubs growing in the district include Akk or Badar, Shisham, Babul, Lasura, Aam, Jamun, jand, KarirPipli etc. and are found widely. The main field crops grown in this area are Rice, Wheat, Maize, Sugarcane, Sorghum etc.

4.3.2 Climate

The climate of the district was characterized by the dryness of the air with an intensely hot summer and a cold winter. The cold season started by late November and extended to about the middle of March. It was followed by hot season, which continued to about the end of June when the south-west Monsoon arrived over the district. The period from July to September was the south-west Monsoon season. The block had a sub-tropical Continental Monsoon climate where seasonal rhythm i.e hot summer, cool winter, unreliable rainfall and great variation in temperature could be seen. Air was dry during greater part of the year. Sometimes dense fog occurred in winter season.

The mean annual rainfall of the district was 624 mm, 76% of the annual rainfall is received during the south-west Monsoon from July-September and the rest was received through 'Western Disturbances' from December to February. Air remained dry during most of the part of the. July was the wettest month of the year with 7.5 rainy days and 169 mm rainfall. January was the coldest month with mean daily maximum temperature 21.3⁰C and mean daily minimum temp 7.3⁰C. May was the hottest month with mean daily maximum temp 26.6⁰C. The mean wind velocity varied from 3.5 km hr⁻¹ during October to 4.3 km hr⁻¹ in April.

4.3.3 Soils

The soil texture is mainly sandy loam, sandy clay and sandy clay loam. The soils belong to order Entisol, suborder fluvents and great group ustifluvents.

4.3.4 Selection of bed planting and zero tillage adopted villages:

A survey was conducted in the Rai block for locating the areas where these RCT's were successful and hence adopted on large scale. During survey it was observed that both these technologies were site specific and hence, for each of these technologies, presence of some specific conditions was responsible for their success in that location (Figure 4.1). Details of these conditions for each technology are given below:

4.3.4.1 Bed planting Technology:

Presence of conditions which made successful adoption of bed planting technology (for vegetable growing) in certain villages of Rai block were as follows :

1. Area had medium texture soils (sandy loam to sandy clay loam)
2. As vegetables required more and frequent irrigations, fresh water was easily available e.g. few village were near Yamuna river or in other adopted villages, water table was not more than 30-40 feet so that water was easily lifted from installed tube wells
3. Irrigation water was nonsaline
4. Area was either plain or had slightly undulating topography but was not low-lying or water logged area.
5. Besides all the villages were easily accessibility to market as they were located near national highway 1(NH1) and therefore all grown vegetables were easily transported to Azadpur Mandi in Delhi.

4.3.4.2 Zero tillage for growing wheat:

Presence of conditions which made successful adoption of zero tillage technology (for wheat growing) in certain villages of Rai block was as follows:

1. Fine textured soil or saline-alkali patches of land where permeability was low
2. Low lying lands where water logging occurred during *kharif* season.

In these areas, surface soil remained moist even at the time of harvest of rice crop in mid-October. By use of zero seed drill farmers could do timely sowing of wheat in mid-november. Since at the time of sowing soil moisture was adequate, it helped in proper germination. Besides due to moist condition, rice residues in the field decayed fast and more organic matter was added to the soil, which improved the porosity and aggregate stability of surface soil. In such areas, conventional tilling of land followed by flat planting was done by marginal farmers only, after the drying of surface soil in late December and due to delay in sowing by more than a month the yield reduction was appreciable.

Soil samples were collected from villages where both resource conservation technologies (RCT's) *i.e.* bed planting and zero tillage were being adopted by most of the medium and big farmers for more than 6-7 years. Villages selected for taking soil samples in farmer's fields practicing bed planting were Badkhalsa, Bahalgarh, Chauhanjoshi, Hasnabad, Jat Joshi, Khewra, Lawanspur, Rathwanda, ParliKalan, Parlikhurd, Mirakpur and Nathupur. Out of 12 selected villages, soil samples were collected in August-September, 2011 (*kharif* season) in 6 villages where Tomato, brinjal, chilli, Pumpkin, Okra and carrot were grown on beds in fields and in other six villages soil observations were taken in February, 2012 where farmers were growing Cabbage, cauliflower, radish, Dhanai, French bean and Beet leaf on beds. In each of the above mentioned village, for comparing bed planting system with conventional system, three soil samples were taken from 0-15 and 15-30 cm soil layers under vegetable planted beds and simultaneously another three samples from three nearby fields where Jowar in *Kharif* and wheat in *rabi* were sown on flat lands after conventionally tilling (2 times harrow+2 times tiller followed by pata).

Soil samples (in triplicate) were also taken from 0-15 and 15-30 cm in the first week of January in farmers' fields where wheat was sown by zero seed drill in mid - November. These villages were Jakoli, Khurrampur, Manoli, Nasirpur, Pabsara and Pritampur. Simultaneously, soil samples (again in triplicate) were also collected from nearby conventionally tilled wheat fields to compare soil properties under zero tilled

wheat with those under conventionally tilled wheat. Since none of the farmers in that area practiced direct sowing of rice without tillage, no observation could be recorded to compare zero tilled rice with conventionally puddled (wet tilled) rice.

Summary of the treatments studied

a. Conventional versus Zero tillage system

Treatment Name	Specification
CTR - CTW	puddled rice followed by conventional tilled wheat
DR /ZR- ZT	Direct seeded rice followed by zero till wheat

b. Conventional versus bed system

CTJ- CTW	Conventionally tilled Jowar in <i>kharif</i> followed by conventional tilled wheat
Veg. on bed-veg. on beds	vegetables on beds in both <i>kharif</i> and <i>rabi</i> season

4.3.5 Soil properties studied:

Soil samples were taken by core auger for determination of soil properties such as pH, electrical conductivity (EC), bulk density (BD), soil texture (by dispersing with water and also by completely dispersing it by using hexametaphosphate), soil organic carbon, saturated hydraulic conductivity (K_s), soil water contents at saturation, field capacity and wilting point Standard. Besides field saturated hydraulic conductivity (K_{fs}) was determined in situ by using Guelph permeameter. Above mentioned properties were determined by standard procedures mentioned in table 4.1.

4.3.5.1 Dry aggregate stability (Chepil, 1962):

To determine dry aggregate stability, large clods (>20 mm) of air-dried samples were broken into smaller fragments along their natural planes of weakness by using gentle manual forces. A 50 g soil aggregates passed through 8mm sieve and retained on 5 mm sieve were put on the top of a nest of sieves of decreasing mesh sizes 5, 2, 1, 0.5 and 0.25 mm clamped on a stand of a dry sieve shaker. The sieve shaker is driven by a ¼ HP geared motor. The sieve table is inclined from the vertical axis and the direction of inclination changes progressively in the clockwise direction. In addition to gyratory motion of table, there was a tapping motion as well. It was operated on 220 volt, 50 HZ, AC supply. After shaking these sieve for 5 minutes, soil

retained on each sieve was collected to obtain the dry weight of six aggregate size fractions: <0.25; 0.25–0.5; 0.5–1; 1–2; 2–5 and >5 mm. Weights of these aggregates remaining on each sieve were used to compute dry sieving mean weight diameter (DS-MWD).

$$\text{DS-MWD} = \sum x_i w_i ;$$

Where w_i is the weight of each aggregate class i in relation to the weight of soil sample taken for analysis, x_i the mean diameter of the class (mm).

4.3.5.2 Wet aggregate stability (Yoder, 1936).

To determine wet aggregate stability, samples were prepared in a manner similar to that for dry aggregate stability determination as mentioned above. 50 g of prepared samples was moistened after transferring it to the top sieve of nest of the sieves (5, 2, 1, 0.5 and 0.25 mm) clamped on a stand attached to a wet sieve shaker. The wet sieve shaker was made to move the nest of sieves up and down in a water filled drum with a frequency of 30-35 cycles per minute and a stroke of 3.8 cm for 5 minutes. After shaking these sieve for 5 minutes, soil retained each sieve was collected to obtain six water stable aggregate size fractions: <0.25; 0.25–0.5; 0.5–1; 1–2; 2–5 and >5 mm. Weights of the aggregates remaining on each sieve were used to compute wet sieving mean weight diameter (WS-MWD).

$$\text{WS-MWD} = \sum x_i w_i ;$$

Where w_i is the oven dry weight of each aggregate class i in relation to the oven dry weight of soil sample taken for analysis, x_i the mean diameter of the class (mm).

4.3.6 Computation of various soil structural stability indices

Calculation of few structural/erodibility indices required determination of calgon (Na hexametaphosphate) dispersed and water dispersed silt+clay. The other important parameter required for computation of few indices was moisture equivalent which was considered equal to soil water content at field capacity. The different erodibility indices calculated were Dispersion ratio, Erosion ratio, Clay moisture equivalent ratio, Clay ratio and Stability index.

1. Dispersion ratio (Middleton, 1930) = % water dispersable (silt+ clay)/ % calgon dispersable (silt+ clay)
2. Erosion ratio (Middleton, 1930) = dispersion ratio/clay moisture equivalent ratio
3. clay moisture equivalent ratio = % clay/% moisture equivalent

4. clay ratio = % (sand+silt) / % clay

5. Stability Index = $S_b - S_a$

S_b = % calgon dispersible (silt+clay)

S_a = % water dispersible (silt+clay)

The higher CMER value is considerably higher for non-erodible than for erodible soils. The higher CMER indicates higher percolation rate and consequently decreasing runoff rate. Dispersion ratio is a function of ease of dispersion and CMER is ease of percolation, hence both these ratios vary inversely.

Mostly soil with DR > 0.15 (15%), ER > 0.1 (10%) and CMER < 1.5 are considered as erodible.

4.3.7 Methodology (Statistical and Geostatistical methods):

4.3.7.1 Statistical analysis:

Descriptive statistical analysis was carried out for K_{fs} , BD, θ_{PWP} , θ_{FC} , θ_{SAT} , AWRC, OC %, sand %, silt % and clay %, DR, DS MWD, WS MWD, CMER, ER and CR.

4.3.7.2 Multiple regression analysis

Multiple regression equations (Pedotransfer functions) were developed for predicting some dependent variables such as; AWRC, DR, DS-MWD, WS-MWD, CMER, ER, CR as a function of OC %, clay %, silt % and sand % K_{fs} and NCP using “Statistica Pro-2008” software package. Since the degree of freedom (df) was large, t value at 5% level of significance if found > 2, was an indication that independent parameter had significant effect on dependent variables, or other way if p value of parameter was < 0.05, then also the parameter was considered to have significant effect on dependent variables.

4.3.8 Result and discussion:

4.3.8.1 Descriptive Statistics:

Statistical analysis of soil data of conventionally planted surveyed site revealed that variation of clay and sand was within 9.6-36% and 41.6-80%, respectively (Table 4. 2). Prominent texture classes of the area included sandy clay loam, sandy loam and sandy clay. In most of the area pH was less than 8.5 and EC was less than < 4 dS/m which indicated that soils were non saline. Range of saturated hydraulic conductivity both in field (K_{fs}) and laboratory (K_s) was variable and average value of K_s in subsurface was lower than that of surface. Similarly, average bulk density (BD) also varied between optimum (1.25 Mg m^{-3}) to higher (1.70 Mg m^{-3}).

Both lower K_s and higher BD in subsurface indicated the presence of compact layer. In some areas, both available water retention capacity (AWRC) and noncapillary pores (NCP) were below their optimum ranges (15% for AWRC and 10% for NCP). Variation in values of dry mean weight diameter (DS-MWD) was relatively less as compared to water stable mean weight diameter (WS-MWD). Range of WS-MWD showed the presence of poor to strong aggregate stability. Results of erosion indices such as dispersion ratio (a measure of ease of dispersion of primary particles) showed that in most of the area the value of DR was >0.15 (0.15 -0.97) which Indicated that soils of this region are prone to erosion. Similarly another ratio termed as colloid moisture equivalent ratio (CMER) (a function of ease of percolation and absorptive power of soil) was also computed. Higher value of this ratio was an indicator of high percolation rate which made the soil less erodible. In most of the surveyed area the value of this ratio was <1 , which confirmed the erodible nature of this region. Both DR and CMER were indicative of erodible nature of soil, and both ratios vary inversely, so a combination was accomplished by dividing DR by CMER and was designated as erosion ratio (ER). Lower value of ER (<1) was indicative of non-erodible nature of soil. Computation of ER showed values more than 0.25 in the study area, which again reconfirmed the erodible nature of soil.

4.3.8.2 Correlation among various structural indices

DS-MWD which was an indicator of aggregates resistance to abrasion by external agencies like wind was not correlated to any of the computed water stable aggregation indices (Table 4.3). The other significant correlations included positive correlation of DR (ratio of water dispersible silt plus clay and total silt plus clay) with ER (ratio of DR to CMER) and CR (ratio of % Sand plus silt and %clay) and its negative correlation with CMER (% clay/moisture equivalent) and stability index (SI) (difference between total silt plus clay and water dispersed silt plus clay). The positive correlation between DR and CR was due to the fact that in both cases total clay % was in denominator and as the soils were non-saline and also non-sodic, higher clay% improved the binding between inter and intra aggregates and reduced the amount of water dispersible clay. On the other hand, the presence of total clay % in denominator in DR and in numerator in CMER was the reason for negative correlation between DR and CMER. Similarly the explanation for negative correlation between DR and SI was that less DR means less water dispersible silt+clay which made SI more.

4.3.8.3 Development of pedotransfer functions:

DS-MWD was not significantly correlated to any of the basic soil parameters such as pH, EC, OC, BD, NCP, Clay % etc.

WS-MWD was negatively correlated to pH and EC, increasing values of which increased dispersion due to more absorption of Na^+ ions by clay colloid and made aggregate unstable (Table 4.4). Again, lower NCP and more clay content favoured stronger inter and intra aggregate bonds. pH, EC, OC, BD, AWC, NCP, clay and sand together accounted for 59% variation in WS-MWD.

As mentioned earlier, even though DS-MWD was not much affected by presence of OC, but it significantly affected WS-MWD i.e. soils with lower OC were less stable and had lower WS-MWD. Thus change in MWD of aggregates was also appreciable. Similarly, positive correlation between CMWD and NCP was due to the fact that higher NCP weakened the inter particle bonding of aggregates and reduced WS-MWD and hence increased CMWD.

Data of mult- regression analysis of DR as a function of soil parameters showed that it was significantly and positively correlated to AWC, NCP and sand and negatively correlated to BD (Table 4.5). Similar results were reported by Korkanc *et al.*, (2008) and Su *et al.*, (2004). Higher AWC and NCP and lower BD means more pore space and weak inter and intra-aggregate bonding hence more dispersion by water. Higher % of total sand on the other hand indicated lower % of total silt+clay (100-%sand), which formed the denominator of DR and therefore made the ratio higher. Higher % of clay improved the binding between the soil particles and made them more resistant to water dispersion thus the amount of water dispersed clay (numerator of DR) became less.

Regression analysis showed that CMER was positively correlated to K_{fs} , pH, NCP and negatively correlated to EC and saturation%. Higher NCP and K_{fs} indicated higher macro-porosity and relatively lower micro-porosity and hence lower field capacity moisture content which resulted in higher CMER (Table 4. 6).

Clay ratio (ratio of % silt plus sand and % clay) was positively correlated to K_{fs} because higher the clay ratio means coarser fraction in soil, and therefore higher K_{fs} (Table 4. 7).

4.3.8.4 Soil physical environment under bed and conventional system:

Organic carbon of 0-15 and 15-30 cm soil layers of bed planted fields varied between 0.47-0.52 % (av. 0.48%) and 0.36-0.46 % (av. 0.42%), whereas that under

conventional planting (CT) varied between 0.32 to 0.44 % (av. 0.40%) and 0.3-0.41 % (av. 0.35 %) (Figure 4.2). The reason for 0.07-0.08 % increase in OC in bed planted system was fewer disturbances due to reshaping the existing beds for at least two seasons.

Similarly for 0-15 and 15-30 cm soil layers, BD varied between 1.34-1.52 and 1.40-1.52 Mg m^{-3} for bed planting system and varied between 1.40-1.55 and 1.45-1.60 Mg m^{-3} for conventional planting system (Figure 4.3). Lower BD of bed planting was due to placement of heap of soil dug from furrow on bed which was pressed lightly by a iron bars while leveling the bed. Similar results had been reported by Cornish *et al.*, 1984, Aggarwal *et al.*, 2006, Gláb and Kulig, 2008. Even at the end of the season, though BD increased in both systems but the BD of bed system remained lower both in surface as well as subsurface.

Not only total porosity in bed system was more as indicated by lower BD, water retention capillary pores (AWC) were also more (2-3%) in bed as compared to conventional system (Figure 4.4). Similar results had been reported by McGarry *et al.*, 2000, Rasmussen, 1999, Bhattacharyya *et al.*, 2006.

In one of the farmer's field in Khurrampur village, soil penetration resistance (PR) (Figure 4.5) measured under coriander planted beds showed lower value in the upper 10cm but higher value in the deeper layers. It was because in the upper 0-10 cm of bed the soil was very loose as compared to conventional system and therefore in spite of the fact that bed was drier, its PR value was lower but in the deeper layers which were more moist under conventional tillage (as it received more irrigation water due to flooding method of irrigation) PR value less. Reading were taken again in another farmer's field in the same village, where fresh beds were made few days before and also in the adjacent land which was a fallow conventionally tilled plot. As there was no irrigation given to both lands, PR remained lower in upper 0-15 cm soil layer in bed as compared to CT. It was even higher in furrow because of compaction due to tractor movement.

4.3.8.5 Structural indices under bed and conventional system:

The DS-MWD and WS-MWD (Figure 4.6) in surface layer under beds varied from 4.46-5.12 mm (av. 4.72 mm) and 1.44-2.16 mm (av. 1.89 mm) while in CT it varies from 4.68-5.53 mm (av. 5.20 mm) and 1.05–1.68 mm (av. 1.57 mm). The WS-MWD was higher by 0.32 mm in case of beds than conventional tillage (CT) because in beds, OC was higher which resulted in more stable aggregates probably due to

hydrophobic and non-wetting nature of organic matter. In contrast, DS-MWD of bed system showed a reverse trend. It might be due to higher organic carbon content of bed which decreased aggregate strength as explained by (Zhang *et al.*, 1993). Besides due to higher aggregate porosity in beds, bonding between inter and intra aggregate became weak which made aggregates more fragile. Thus CMWD was lower in case of Beds than CT. Similar results had been reported earlier (De Ploey and Poesen, 1985, Baldock and Kay, 1987, Hermawan and Cameron, 1993, Zhang *et al.*, 1994).

The dispersion ratio (Figure 4.7) in beds varied from 0.05–0.72 with an average of 0.42 while in CT it varied from 0.30–0.98 with an average of 0.66. The lower dispersion ratio in beds was an indicator of improvement in aggregate stability. Similarly the erosion ratio in beds varied from 0.04–1.3 with an average of 0.28, while in CT it varied from 0.33–1.44 with an average of 0.52. Thus, lower erosion ratio in beds in most of the surveyed sites showed that bed system reduced eroding tendency of these soils. Again in most of the soils, the magnitude of CMER was higher in beds (0.6–1.65, av. 1.1) as compared to conventional (0.4–1.1, av. 0.75) which was again reconfirmed the effectiveness of bed planting technology in improving soil structure. Similarly clay ratio was lower (1.6–5.2, av. 2.38) and stability index was higher (6–55, av. 34) in beds than conventional system (CR with range 2.37–7.33 and av. 4.25) and SI with range 1.6–36, av. 20.23 (Figure 4.8). Wischmeier and Mannering, 1969, Singh and Prakash, 1985, Kukal *et al.*, 1993, also reported similar findings for different land uses.

4.3.8.6 Soil physical properties and structural indices under zero (ZT) and conventional system (CT):

The bulk density under ZT in upper 0–15 cm varied from 1.40–1.50 Mg m⁻³ and in CT it varied from 1.44–1.58 Mg m⁻³. The lower bulk density in zero tillage as compared to conventional tillage was due to improvement of organic matter added through crop residues of previous crop (Figure 4.9). The bulk density in lower 15–30 cm in zero and conventional tillage varied between 1.42–1.52 Mg m⁻³ and 1.54–1.64 Mg m⁻³ respectively. The higher bulk density in lower 15–30 cm was due to formation of compacted sub surface layer. Similar results had been reported by Sharma and De Datta, 1985, Aggarwal *et al.*, 1995, Hobbs and Gupta, 2002. Soil organic carbon (OC) of surface layer under ZT (Figure 8) varied from 0.5–0.7% (av. 0.55%) but under CT varied from 0.39–0.5 % (0.4%) (Figure 4.10). The higher OC in case of ZT was due to rotting of crop residues of previous crop and least soil disturbance due to direct

sowing of wheat crop. Similar results have been reported by Dick *et al.*, 1991, Chauhan *et al.*, 2002, Bhattacharyya *et al.*, 2006 and Panday *et al.*, 2008. The AWC in ZT varied from 15-21 cm/m but in conventional tillage it was 13-17 cm/m. The higher AWC in case of ZT was due to more plant residues were left on the soil surface which led to increase in OC and porosity (Figure 4.11). Other workers also reported similar results (Blevins and Frye, 1993, Rasmussen, 1999, McGarry *et al.*, 2000, Bhattacharyya *et al.*, 2006).

In Pritampura and Jhakauli villages, where texture of soils was fine (sandy clay loam and sandy clay) and most of the cultivated lands were low lying, water logging was a common problem during *Kharif* and even after the harvest of Paddy in end of October, soil remained moist. Hence for past 7-8 years, wheat was sown by zero seed drill in middle of November by some farmers whereas few farmers sow their fields in middle of December after conventional tilling their drier fields. At the time of taking observations of soil penetration resistance (Figure 4.12), both zero tilled as well conventionally tilled fields were not irrigated for past three weeks and looked dry from surface. In zero tilled area due to more amount of decomposed crop residue in upper 0-15 cm soil, it was less compact as evident from lower soil PR although soil water content of both soils was low. Similar results were reported by (Carman 1997 and Bhattacharyya *et al.*, 2006).

Important aggregation index, WS-MWD increased from 1.28 mm under CT to 1.58 mm under ZT because in ZT organic carbon was higher which resulted in more stable aggregates probably due to hydrophobic and repellent nature of organic carbon, while DS-MWD of ZT showed a reverse trend. It was mainly because higher organic carbon content decreases aggregate strength. Besides due to higher total porosity due to lower BD in ZT, bonding between inter and intra aggregate became weak which made aggregates more fragile. Several other workers also reported similar results (e.g., De Boodt 1974, Baldock and Kay, 1987, Hermawan and Cameron, 1993, Zhang *et al.*, 1993, Ternan *et al.*, 1996). Thus CMWD was lower in ZT (2.70 mm) than in CT (3.39 mm).

The dispersion ratio (Figure 4.13) varied from 0.27–0.69 (av. 0.56) in ZT while it varied from 0.45–0.98 (av. 0.74) in CT. The lower dispersion ratio in ZT was an indicator of improvement in aggregate stability. Similarly lower erosion ratio in ZT (0.46) in most of the surveyed sites showed that zero tillage system reduced eroding tendency of these soils. Again in most of the soils, the magnitude of CMER was

higher in zero tillage as compared to conventional which again reconfirmed the effectiveness of zero tillage system in improving soil structure. Similarly clay ratio was lower and stability index was higher in zero tilled system than conventional system. The decrease of ER and CR from 0.63 and 5.99 under CT to 0.46 and 3.86 under ZT indicated improved aggregation under zero tillage. Similarly increase in CMER and SI from 0.66 and 9.21 under CT to 0.7 and 20.4 under ZT also indicated improved soil structure condition by adoption of zero tillage. Similar comparisons had been made by (Wischmeier and Mannering 1969, Singh and Prakash 1985, Kukal *et al.*, 1993) under different land uses.

4.4 Conclusion:

Analysis of the aggregate stability of the soils of surveyed area (Rai block of Sonapat district) had clearly revealed that these alluvial plain soils near river Yamuna were highly erodible in nature. The main physical constraints were low organic matter, low sub surface permeability and poor aggregate stability. These constraints could be alleviated through the adoption of appropriate resource conservation technologies, which over a period of time could add more carbon in soil through more residue incorporation and less disturbance to the soil. Structural stability measured through index like WS-MWD showed improvement in aggregate stability under RCT's. Other erosion indices such as DR, ER and CR were less and CMER and SI were more in bed and ZT as compared to conventional system which revealed that adoption of RCT's in this region would make the soils more resistant to erosion.

5. RESEARCH PAPER-2

Correlation among various soil structural indices and crop productivity

5.1 Abstract

In order to assess the production potential of soils of Rai block of Haryana region a survey was conducted in 25 villages and soil samples were collected and analyzed for important soil properties. Prediction maps of bulk density (BD), available water capacity (AWC), organic carbon (OC), non-capillary porosity (NCP) and saturated hydraulic conductivity (K_{fs}/K_s) were prepared using inverse distance weighting technique in Arc GIS and physical rating index map of the area was prepared to present the soil physical constraints and overall production potential of the different parts of the study area. It was observed that instead of interpolating the parameter at all unvisited sites of block, interpolation should be done in 1-2 km periphery around the surveyed points as it would present more realistic results with lower RMSE value than doing interpolation for the entire block.

Besides important structural indices such as dispersion ratio (DR), erosion ratio (ER), Clay ratio (CR), Clay moisture equivalent ratio (CMER) and stability index (SI) were computed and wheat grain yield was collected at all surveyed sites. Results revealed that 60% of the soil in the surface and sub surface had SOC <0.45% which indicated that the soils were deficient in organic matter. In 50% of the area, higher BD indicated that sub surface soil was compacted. Again, nearly 60% of the area had sub surface K_s below the optimum range (1-3 cm/hr.) which again confirmed the presence of hard pan. AWC of the surface soil of most of the area was within optimum range (>15%) but in the subsurface only 32% of the area had AWC in the optimum range. Computation of PI of this region indicated that 50-60% of area had medium production potential (range of PI between 0.5-0.6) and rest of the region had low to very low production potential (PI <0.5).

Determination of structural indices such as DR and ER showed more than 50% of area was erosion prone. Correlation between different erosion indices and crop yield were significant and analysis indicated that DR, ER, CR were negatively correlated, whereas SI and CMER were positively correlated to wheat grain yield. The above results thus confirmed that poor yields were due to poor structural condition of these soils.

5.2 Introduction

Soil structure is a complex soil property, partly related to inherent characteristics of particle size and clay mineralogy and partly to anthropogenic influences related to land use and management. According to Kay and Angers (2001), soil structure can be described in terms of: (i) structural form; the heterogeneous arrangement of pores and solids at any given time; (ii) structural stability, the ability of soil to retain its structural form after exposure to stress and (iii) structural resilience: the ability of soil to recover its structural form through natural processes. Soil structural form may be described visually in terms of the size, shape and porosity of individual units of structure (aggregates) to which additional physical properties such as strength and stability can be added. However, from such a description, it may be difficult to derive an indication of the quality of the structure for agricultural production.

For computing the potential productivity loss due to soil erosion (Neill, 2003), soil quality was presented in terms of Productivity index (PRI). The PRI model rated soils on the sufficiency for root growth based on potential available water storage capacity, bulk density, aeration, pH, and electrical conductivity.

In past many more indices of structure were developed, based on laboratory tests for stability of individual aggregates, their dispersion in water or pore size distribution or on field permeability assessments, for example those of Low (1954), Childs *et al.*, (1957), Williams and Cooke (1961) and Currie (1965). Aspects of soil structure are commonly described and quantified from water retention, water and gas permeability, gas diffusivity and aggregate stability (De Boodt *et al.*, 1967, Kay and Angers, 2001). More recent methods involve micromorphology (Ringrose-Voase, 1991), 3D visualization and advanced modelling (Young and Crawford, 2004).

Physical rating index (PI) by Gupta and Abrol (1993) was also another index used in soil physical constraint analysis and for assessing the production potential of soils. It was one step beyond land capability classification. In this method, in addition to basic soil physical parameters, few more dynamic parameters such as bulk density, infiltration rate, soil organic matter, water table depth and available water storage capacity were used for physical constraint identification along with the estimation of relative magnitude of their severity. Accordingly, the production potential of these soils was predicted under optimum levels of water and fertilizer inputs along with the adoption of appropriate plant protection measures. Efficiency of any suggested

management practice for alleviating these constraints could be assessed in terms of changes in its rating value and hence its production potential (Aggarwal and Choudhury, 2005).

Site-specific crop and soil management often incorporates precise spatial information about soil properties across farm fields to help meet the goal of optimizing inputs use while maintaining or increasing yields (Huang and Jin, 2002, Huang *et al.*, 2006). Knowledge of the structural stability of soils is important in evaluating the crusting/sealing potential of soils, soil permeability, steady-state infiltration rates, soil erosion and seedling emergence and in predicting the capacity of soils to sustain long-term crop production.

Hence, there is a need for computing soil erodibility indices in farmer's fields where such technologies are being practiced from past several years for monitoring the impact of these RCT's on soil structural stability, overall soil physical health and productivity of land. Thus the current study was conducted with the objective to find out correlation between crop productivity and different soil structural indices for studying the influence of aggregate stability on crop productivity.

5.3 Material and Methods

5.3.1 Study Area

The present study was conducted in Rai block of Sonapat district in Haryana located at 28°48'15" to 29°17'10" north latitude and 76°28'40" to 77°12'45" east longitude and at an altitude of 228 m above mean sea level. Rai block is a part of eastern Haryana plain (Trans Indo-Gangetic alluvial plains), more specifically a part of Yamuna recent alluvium plains. It is because, on its eastern boundary, Yamuna River flows and on its western boundary Delhi branch of western Yamuna canal is present.

5.3.2 Climate

The climate of study area was semi-arid, subtropical with extreme hot summer and cool winter. The cold season started by late November and extended to about the middle of March. It was followed by hot season, which continued to about the end of June when the south-west Monsoon arrived over the district. The period from July to September was the south-west Monsoon season. The mean annual rainfall of the district was 624 mm, 76% of the annual rainfall is received during the southwest monsoon from July-September and the rest was received through 'Western Disturbances' from December to February. July was the wettest month of the year.

January was the coldest month with mean daily maximum temperature 21.3°C and mean daily minimum temp 7.3°C. May was the hottest month with mean daily maximum temp 26.6°C. The mean wind velocity varied from 3.5 km hr⁻¹ during October to 4.3 km hr⁻¹ in April.

5.3.3 Soils

The soils of study area belonged to order Entisol, suborder fluvents and great group ustifluvents. The soil texture was mainly sandy loam and sandy clay loam.

5.3.4 Soil properties studied:

Soil samples were taken by core auger for determination of soil properties such as pH by pH meter, electrical conductivity (EC) determined by EC meter, bulk density (BD) by Core method, soil texture by international pipette method, soil organic carbon by Walkley and Black (1934) method, saturated hydraulic conductivity (K_s) measured in the laboratory by constant head permeameter. Field capacity and wilting point were determined by pressure plate apparatus. Besides field saturated hydraulic conductivity (K_{fs}) was determined in situ by using Guelph permeameter. An aggregate stability index such as DS-MWD and WS-MWD was determined by dry and wet sieving (Chepil, 1962 and Yoder, 1936).

Undisturbed soil samples (in triplicate) were collected from 25 villages (Figure 1) at two depths (0-15 and 15-30 cm) during the maturity of wheat crop in February, 2012.

5.3.5 Computation of various soil structural stability indices

Calculation of few structural/erodibility indices required determination of calgon (Na hexametaphosphate) dispersed and water dispersed silt+clay. The other important parameter required for computation of few indices was moisture equivalent which was considered equal to soil water content at field capacity. The different erodibility indices calculated were -Dispersion ratio, Erosion ratio, Clay moisture equivalent ratio, Clay ratio and Stability index.

1. Dispersion ratio (Middleton, 1930) = % water dispersable (silt+ clay)/ % calgon dispersable (silt+clay)
2. Erosion ratio (Middleton, 1930) = dispersion ratio/clay moisture equivalent ratio
3. Clay moisture equivalent ratio = % clay/% moisture equivalent
4. Clay ratio = % (sand +silt) / % clay
5. Stability Index = $S_b - S_a$
 S_b = % calgon dispersable (silt+clay)

S_a = % water dispersable (silt+clay)

The higher CMER value is considerably higher for non-erodible than for erodible soils. The higher CMER indicates higher percolation rate and consequently decreasing runoff rate. Dispersion ratio is a function of ease of dispersion and CMER is ease of percolation, hence both these ratios vary inversely.

Mostly soil with $DR > 0.15$ (15%), $ER > 0.1$ (10%) and $CMER < 1.5$ are considered as erodible.

5.3.6 Methodology for computing soil physical health index (PI):

In physical rating method (Gupta and Abrol, 1993 and Ali *et al.*, 2011), parameters such as bulk density, saturated hydraulic conductivity, soil organic carbon, available water storage capacity, non-capillary pores, were used for determining the production potential of soils. For a given site, each of these parameters was assigned a rating value corresponding to its actual value by referring to rating chart (Table 1). Each of this parameter was given a score of 1 if the parameter value lies within the optimum range. If the value lies below or above the critical limit, a score less than 1 were given. Greater the deviation of parameter value from optimum range, lesser the score given to it. The product of rating values of all the eight parameters gave the physical rating index.

PI was an indicator of overall soil physical health status. For range of PI > 0.75 , $0.50-0.75$, $0.25-0.50$ and < 0.25 , soil physical health status and accordingly its production potential could be labeled as very good, good, medium or poor, respectively.

5.3.7 Preparation of prediction maps:

Maps for the study area were prepared using geo-processing tools of Arc GIS software. To prepare prediction maps, firstly three vector shape files- one point file (for preparing data attribute table), one line file (for showing roads and canal) and two polygon files (for showing block boundary and village boundaries) were created in Arc Catalogue and were added to a new Arc Map. In next step, scanned map of Rai block was geo-referenced in Arc Map. After that, vector files were digitizing for Rai block *i.e.* block boundary, 25 village boundaries, roads, rivers and canals. Sampled data points, collected using GPS with latitude and longitude for each location, were also digitized and added in the map as an attribute table. All the measured and computed soil properties and indices were added as separate fields in this attribute table and prediction maps (smooth 2D-surfaces) of each property was generated using

most widely used interpolation technique inverse distance weighting method (IDW). Prediction maps are actually filled contour maps showing different ranges of the given parameter with different colours. Values of BD, AWC, K_{fs} , OC and NCP were divided into ranges similar to those given in physical rating method and appropriate rating values were assigned to them. Physical rating index (PI) at each sampling point was determined by multiplying the rating values for all five parameters.

$$PI = R_{BD} \times R_{AWC} \times R_{K_{fs}} \times R_{OC} \times R_{NCP}$$

Where R_{BD} , R_{AWC} , $R_{K_{fs}}$, R_{OC} and R_{NCP} were rating values for BD, AWC, K_{fs} , OC and NCP.

Reason for multiplication of individual rating values for defining the PI was that this index was an indicator of soil productivity. Large deviation in any of the individual parameter value from its optimum range could bring down the yield drastically and such a response could only be observed if the rating values of individual parameters were multiplied. Lastly, these soil maps were subjected to raster map calculations (based on arithmetic, Boolean and relational operators) to compute percentage of total area under different ranges.

5.4 Results and discussion;

For preparing prediction/interpolated maps of all important soil parameters and indices, inverse distance weighting was chosen as the most appropriate interpolation technique. Kriging could not be used for interpolation because the sampling interval was between 1-3 km which was more than the range of most of the soil parameters. It was realized that instead of interpolating the parameter at all unvisited sites of block, interpolation should be done in 1-2 km periphery around the surveyed points as it would present more realistic results with lower RMSE value than doing interpolation for the entire block.

Prediction map of soil texture showed that the soils of the study area belonged to the major order Entisol and suborder fluvents. The soil texture was mainly sandy loam, sandy clay loam and sandy clay soil (Figure 5.1). Sandy clay loam soils covered 54.3%, sandy clay 23.5% and sandy loam 22.2% of the total area. Nearly 72.1% of the total area has pH between 8.0-8.5 and rest 29.1% had pH between 7.5-8.0 (Figure 5.2). About 86.9% of total area has EC around 2-4 ds/m and the remaining area have EC around 4-6 ds/m. Results thus revealed that most of the soils were non-saline as pH was found < 8.5 and EC < 4dS/m.

Soils of the area were deficient in organic carbon ($<1\%$) (Figure 5.3). OC of both surface and subsurface layers in majority of area (88%) had values ranged between 0.30-0.60 percent. Prediction maps of soil BD (Figure 5.4) of surface layer showed that 90% of the total area in upper 0-15 cm, was within optimum values ($1.25\text{--}1.45\text{ Mg m}^{-3}$). In lower 15-30 cm, BD was above the optimum range ($1.45\text{--}1.70\text{ Mg m}^{-3}$). The higher BD of the subsurface is indicated the formation of compact layer in the sub surface due to intensive tillage operations.

Saturated hydraulic conductivity of the surface layer was measured in situ and lab both and that of subsurface 15-30 cm was measured in lab only. Measured value of K_{fs} was significantly higher than that of K_s , which were mainly because in field, hydraulic gradient existed both in vertical as well as horizontal direction, while as, in lab hydraulic gradient is only in vertical direction. Regression analysis between both parameters showed that K_{fs} was nearly 30 times of K_s . K_{fs} and K_s measured for surface and subsurface soils (Figure 5.5) showed that nearly 60 % of the surveyed area had values below optimum range ($<15\text{ cm/hr}$ for K_{fs} and 0.5 cm/hr for K_s).

It has been found that 80% of surface soil had AWC in optimum range ($>15\%$) (Gupta, 1986), whereas majority (68%) of subsurface soil had AWC below optimum range ($<10\%$) (Figure 5.6). Again, nearly 83% of surface soil had $\text{NCP} > 10\%$ (critical limit of soil aeration) (da Silva and Kay, 1997), whereas only 56% of subsurface soil had $\text{NCP} > 10\%$. The analysis thus revealed that nearly 45-50% area had poor aeration in subsurface (Figure 5.7).

Physical rating index (PI) at each surveyed site was computed by multiplying the rating values of BD, OC, AWC, NCP and K_s or K_{fs} (Table 5.1). Prediction map of PI showed that for surface layer, 58% area had medium production potential (PI between 0.5-0.6) and 25% had good production potential (PI between 0.6-0.8) (Figure 5.8). On the other hand for subsurface, nearly 51% had medium production potential and rest had poor and very poor production potential.

WS-MWD of 47% of surface and only 25% of subsurface had value $>1.5\text{ mm}$ (Figure 5.9), whereas 43% of surface 53% of subsurface had value s between 1-1.5mm. Lower WS-MWD in the subsurface was due to lower organic carbon. Nearly 77% of surface soils had DS-MWD $>5\text{ mm}$ (Figure 5.11). Map of both dispersion ratio (DR) and erosion ratio (ER) showed that 73% of the total area had DR and ER >0.5 (Figure 5.10). These maps thus showed that soils of this region were erodible in nature.

5.4.1 Correlation among different structural indices:

DS-MWD which was an indicator of aggregates resistance to abrasion by external agencies like wind was not correlated to any of the computed water stable aggregation indices (Table 5.2). The other significant correlations included positive correlation of DR (ratio of water dispersible silt plus clay and total silt plus clay) with ER (ratio of DR to CMER) and CR (ratio of % Sand plus silt and % clay) and its negative correlation with CMER (% clay/moisture equivalent) and stability index (SI) which is the difference between total silt plus clay and water dispersed silt plus clay. The positive correlation between DR and CR was due to the fact that in both cases total clay % was in denominator and as the soils were non-saline and also non-sodic, higher clay % improved the binding between inter and intra aggregates and reduced the amount of water dispersible clay. On the other hand, the presence of total clay % in denominator in DR and in numerator in CMER was the reason for negative correlation between DR and CMER. Similarly the explanation for negative correlation between DR and SI was that less DR means less water dispersible silt+clay which made SI more.

5.4.2 Correlation of soil erodibility and aggregate stability indices with physical rating index and yield of crops

On correlating different aggregate stability indices and wheat grain yield, it was observed that erosion ratio and clay ratio were negatively and significantly correlated to wheat grain yield (Table 2). These results clearly indicated that poor soil structure leads to poor crop yields. Other significant positive correlation was between SI and yield, which again confirmed the fact that stable structure is necessary for good crop yield. Linear regression analysis of PI and wheat grain yield data showed a good correlation ($R^2=0.71$). The results thus supported earlier findings (Neill, 1979; Pierce *et al.*, 1983 and Ali *et al.*, 2011) that good soil physical health is essential for optimum sustained crop production (Figure 5.12).

5.5 Conclusion:

Physical rating index (PI) method is most suited for soil physical constraint identification and also for accessing the production potential of soil at a given site. Prediction map of PI showed medium to poor production potential of these soils. Computation of various indices such as DR, ER and SI indicated that these soils near the bank of river Yamuna had poor structure and were highly erodible in nature. Again

good correlation between structural indices and PI indicated that poor structural conditions were mainly responsible for poor production potential of these soils.

6. DISCUSSION

Long term effect of different resource conservation technologies (RCT's) on basic soil properties indicated lower bulk density (BD) in zero tillage (ZT) as compared to conventional tillage (CT) mainly because of improvement in soil organic matter status due to its low decomposition under undisturbed conditions. The another reason for higher OC in case of ZT could be due to rotting of crop residues of previous crop which resulted in more humus formation leading to improved overall soil porosity. Similar results have been reported by (Dick *et al.*, 1991, Chauhan *et al.*, 2002, Bhattacharyya *et al.*, 2008 and Panday *et al.*, 2008). Similarly, lower BD in another widely adopted RCT *i.e.* bed planting was due to bed making technique. During bed making, heap of soil dug from furrow was placed on bed and was subsequently pressed lightly by an iron bar while leveling the bed. Similar results had been reported by (Cornish *et. al.*, 1984, Aggarwal *et. al.*, 2006 and Głáb and Kulig 2008). Loose soil condition in both RCT's was further confirmed by lower soil penetration resistance under them as compared to conventional system. Higher porosity in both RCT's resulted in higher available water retention capacity (AWC). Soil structural stability which is very important for proper water-air balance in soil for sustained crop growth could be assessed by measuring various structural indices such as wet sieving mean weight diameter (WS-MWD), reduced dispersion ratio (DR), erosion ratio (ER) and clay ratio (CR).

Among different structural indices, significant correlations included positive correlation of DR (ratio of water dispersible silt plus clay and total silt plus clay) with ER (ratio of DR to CMER) and CR (ratio of % Sand plus silt and % clay) and its negative correlation with CMER (% clay/moisture equivalent) and stability index (SI) which is the difference between total silt plus clay and water dispersed silt plus clay. The positive correlation between DR and CR was due to the fact that in both cases total clay % was in denominator and as the soils were non-saline and also non-sodic, higher clay % improved the binding between inter and intra aggregates and reduced the amount of water dispersible clay. On the other hand, the presence of total clay % in denominator in DR and in numerator in CMER was the reason for negative correlation between DR and CMER. Similarly the explanation for negative correlation between DR and SI was that less DR means less water dispersible silt +clay which would make SI more. Dry sieving mean weight diameter (DS-MWD) which was an

indicator of aggregates resistance to abrasion by external agencies like wind was not correlated to any of the computed water stable aggregation indices.

Regression analysis showed that wet sieving mean weight diameter (WS-MWD) was negatively correlated to pH and EC, increasing values of which increased dispersion due to more absorption of Na^+ ions by clay colloid and made aggregate unstable. Again, lower NCP and more clay content favored stronger inter and intra aggregate bonds. Presence of OC did not affect DS-MWD, but it significantly affected WS-MWD *i.e.* soils with lower OC were less stable and had lower WS-MWD. Thus change in MWD of aggregates was also appreciable. Similarly, positive correlation between CMWD and NCP was due to the fact that higher NCP weakened the inter particle bonding of aggregates and reduced WS-MWD and hence increased CMWD. Data of multi-regression analysis of DR as a function of soil parameters showed that it was significantly and positively correlated to AWC, NCP and sand and negatively correlated to BD. Higher AWC and NCP and lower BD means more pore space and weak inter and intra-aggregate bonding hence more dispersion by water. Higher % of total sand on the other hand indicated lower % of total silt +clay ($100 - \%\text{sand}$), which forms the denominator of DR and therefore make the ratio higher. Higher % of clay improves the binding between the soil particles and makes them more resistant to water dispersion thus the amount of water dispersed clay (numerator of DR) becomes less. Regression analysis also showed that CMER was positively correlated to K_{fs} , pH, NCP and negatively correlated to EC and saturation%. Higher NCP and K_{fs} indicated higher macro-porosity and relatively lower micro-porosity and hence lower field capacity moisture content which resulted in higher CMER. Clay ratio (ratio of % silt plus sand and % clay) was positively correlated to K_{fs} because higher the clay ratio means coarser fraction in soil, and therefore higher K_{fs} .

The overall soil physical environment improvement in both RCT's was further shown through increased structural stability. The Improved soil OC in RCT's increased WS-MWD, reduced DR, ER and CR in comparison to CT which clearly indicated reduced eroding tendency of these soils by adoption of such resource conservation technologies.

In most of the area, the value of DR was >0.15 which indicated that soils of this region were prone to erosion. Computed value of CMER in most of the surveyed area had value < 1 , which confirmed the erodible nature of this region. Both DR and CMER are indicative of erodible nature of soil, and both ratios vary inversely, so a

combination was accomplished by dividing DR by CMER and was designated as erosion ratio (ER). Computation of ER of the study area also showed higher values (>0.15), which again reconfirmed the erodible nature of soil of this region.

Prediction maps of bulk density (BD), available water capacity (AWC), organic carbon (OC), noncapillary porosity (NCP) and saturated hydraulic conductivity (K_{fs}/K_s) were prepared using inverse distance weighting technique in Arc GIS. Instead of interpolating the parameter at all unvisited sites of block, interpolation was done in 1-2 km periphery around the surveyed points which gave more realistic results with lower RMSE value than doing the interpolation for the entire block. Prediction maps of all relevant parameters were overlaid to prepare physical rating index map of the area so as to present the soil physical constraints and overall production potential of the different parts of the study area. On correlating different aggregate stability indices and wheat grain yield, it was observed that erosion ratio and clay ratio (indicators of eroding tendency of soil) were negatively and significantly correlated to wheat grain yield. These results clearly indicated that poor soil structure led to poor crop yields in that area. Other significant positive correlation was between Stability index and yield, which again confirmed the fact that aggregate stability was directly linked to crop productivity.

7. SUMMARY AND CONCLUSIONS

A study was conducted in farmers' fields of Rai block of Sonapat district to study the long term impact of two widely adopted resource conservation technologies (RCT's) namely bed planting and zero tillage on structural properties of soils (belonging to order Entisol) of recent alluvium plains of river Yamuna. Vegetables growing bed planted areas mostly had medium texture soils, easy access to market and availability of fresh water. Zero tillage was practiced mainly by farmers to timely sow wheat in fine textured soils and low lying areas where soils do not dry even in mid-November.

Aggregate mean weight diameter by dry sieving and wet sieving (DS-MWD and WS-MWD) under different RCT's were studied to compare structural condition of the soils under continuous use of these technologies. Other important structural indices such as dispersion ratio (a measure of ease of dispersion) (DR), colloid moisture equivalent ratio (a measure of ease of percolation) (CMER), erosion ratio (EI), stability index (SI), clay ratio (CR) were also studied to monitor the susceptibility of soil to erosion.

Salient findings of the above study are as follows:

- DR was positive correlated with ER (ratio of DR to CMER) and CR (ratio of % Sand plus silt and % clay) and negative correlated with CMER (% clay/moisture equivalent) and stability index (SI).
- In most of the area the values of DR and ER were >0.15 which Indicated that soils of this region are prone to erosion.
- Similarly another ratio such as colloid moisture equivalent ratio (CMER) which is a function of ease of percolation and absorptive power of soil had value <1 , which confirmed the erodible nature of this region.
- Long term adoption of bed planting and zero tillage (for more than 6 -7 years) resulted in more soil organic carbon build up which helped in more stable aggregate formation as indicated by higher WS-MWD in these resource conservation technologies as compared to conventional tillage.

- Besides the magnitude of both DR and ER was less and CMER was more in bed and ZT as compared to conventional system which revealed that adoption of RCT's in this region will make the soils more resistant to erosion.

Soil physical constraint analysis by preparing prediction maps of soil properties such as AWC, OC, BD, K_{fs} , NCP and physical rating index(PI) by using inverse distance weighting method revealed-

- Instead of interpolating the parameter at all unvisited sites of block, interpolation should be done in 1-2 km periphery around the surveyed points as it would present more realistic results with lower RMSE value than doing interpolation for the entire block.
- 60% of the soil in the surface and subsurface had SOC <0.45% which indicated that the soils are deficient in organic matter.
- 50% of sub surface soil was compacted and nearly 60% of the area had sub surface K_s below the optimum range (1 -3 cm/hr) which indicated the presence of hard pan.
- AWC of the surface soil of most of the area was within optimum range (>15%) but in the subsurface only 32% was in the optimum range.
- Computation of PI of this region indicated that 50-60% of area had medium production potential (range of PI between 0.5-0.6) and rest of the region had low to very low production potential (PI <0.5).
- Correlation between different erosion indices and crop yield was significant. Erosion ratio and clay ratio were negatively correlated whereas SI was positively correlated to wheat grain yield. The above results thus indicated that stable structure is necessary for sustainable higher yield.

Conclusions:

Analysis of the aggregate stability of the soils of surveyed area (Rai block of Sonapat district) has clearly revealed that these alluvial plain soils near river Yamuna were highly erodible in nature. The main physical constraints were low organic matter, low sub surface permeability and poor aggregate stability. These constraints could be alleviated through the adoption of appropriate resource conservation

technologies, which over a period of time added more carbon in soil through more residue incorporation and less disturbance to the soil. Structural stability measured through index like WS-MWD showed improvement in aggregate stability under RCT's. Other erosion indices such as DR, ER and CR were less and CMER and SI were more in bed and ZT as compared to conventional system which revealed that adoption of RCT's in this region will make the soils more resistant to erosion.

Physical rating index (PI) method is most suited for soil physical constraint identification and also for accessing the production potential of soil a given site. Prediction map of PI showed medium to poor production potential of these soils. Computation of various indices such as DR, ER and SI indicated that these soils near the bank of river Yamuna had poor structure and were highly erodible in nature. Again good correlation between structural indices and PI indicated that poor structural conditions were mainly responsible for poor production potential of these soils.

8. ABSTRACT

Impact of Resource Conservation technologies on soil structural properties in Rai block of Sonapat district of Haryana

A study was conducted in farmer's fields of Rai block of Sonapat district to study the long term impact of two widely adopted resource conservation technologies (RCT's) namely bed planting and zero tillage on structural properties of soils of recent alluvial plains of river Yamuna. Aggregate mean weight diameter by dry sieving and wet sieving (DS-MWD and WS-MWD) under different RCT's were studied to compare structural condition of the soils under continuous use of these technologies. Other important structural indices such as dispersion ratio (DR, a measure of ease of dispersion), colloid moisture equivalent ration (CMER, a measure of ease of percolation), and erosion ratio (EI), and stability index (SI), clay ratio (CI) were also studied to monitor the susceptibility of soil to erosion.

Results revealed that in the surveyed villages under conventional tillage the average magnitude of DR and ER were 0.58 and 0.82, respectively, and CMER was <1, which indicated the erodible nature of these soils. Analysis of data of bed and conventional systems revealed that on an average, there was 0.07-0.08% increase in OC in bed planted system as compared to conventional system. It was mainly due to fewer disturbances in soil because of reshaping of beds for next two seasons before making fresh beds. Improved soil OC in bed system increased WS-MWD (1.89 mm) as compared to CT (1.57 mm). The decrease of DR, ER and CR from 0.66, 0.52 and 4.25 under CT to 0.42, 0.28 and 2.38 under beds indicated reduced eroding tendency of these soils under bed planting. Similarly increase in CMER and SI from 0.75 and 20.2 under CT to 1.1 and 34 under bed also indicated improvement in soil structural condition by bed planting. Comparison of soil data of ZT and CT showed improvement in OC, AWC and reduction in BD and PR as compared to CT. Improved soil OC in ZT increased WS-MWD (mm) as compared to CT. The decrease of DR, ER and CR under ZT in comparison to CT indicated improved aggregation under zero tillage. Thus in nutshell it was concluded that by adopting suitable RCT's soil carbon and aggregation were improved and soils became more resistant to erosion.

In order to assess the production potential of soils of Rai block of Haryana region, physical rating index method was used. Results revealed that 60% of the soil in the surface and sub surface had SOC <0.45% which indicated that the soils were deficient in organic matter. It had been found that around 50% of sub surface soil was

compacted and nearly 60% of the area had sub surface K_s below the optimum range (1-3 cm/hr) which confirmed the presence of hard pan. AWC of the subsurface of only 32% area was within optimum range ($>15\%$). Computation of PI of this region indicated that 50-60% of area had medium production potential (range of PI between 0.5-0.6) and rest of the region had low to very low production potential ($PI < 0.5$).

Determination of structural indices such as DR and ER showed more than 50% of area was erosion prone. Correlation between different erosion indices and crop yield were significant and analysis indicated that dispersion ratio, erosion ratio and clay ratio were negatively correlated to wheat grain yield. The above results thus confirmed that poor yields were due to poor structural condition of these soils.

ABSTRACT (HINDI)

हरियाणा के सोनीपत जिले की राय ब्लॉक में संसाधन संरक्षण प्रौद्योगिकियों का मिट्टी के संरचनात्मक गुणों पर प्रभाव

सारांश

सोनीपत जिले के राय ब्लॉक के किसानों के खेतों में दो व्यापक रूप से अपनायी गयी संसाधन संरक्षण प्रौद्योगिकियों मुख्यतः बिस्तर रोपण और शून्य जुताई प्रौद्योगिकी का हाल ही में यमुना नदी के जलोढ़ मैदानों की मिट्टी के संरचनात्मक गुणों पर के दीर्घकालिक प्रभाव का अध्ययन आयोजित किया गया। इन प्रौद्योगिकियों के निरंतर उपयोग के अंतर्गत मिट्टी की संरचनात्मक हालत की तुलना करने के लिए कुल शुष्क वजन व्यास और विभिन्न संसाधन संरक्षण के तहत नम सिविंग (डी एस-एम डब्ल्यू डी एवं डब्ल्यू एस -एम डब्ल्यू डी) द्वारा अध्ययन किया गया। अन्य महत्वपूर्ण संरचनात्मक सूचकांक, के रूप में फैलाव अनुपात (डी आर), कोलाइड नमी समतुल्य अनुपात (सीएमइआर), कटाव अनुपात (ईआइ), स्थिरता सूचकांक (एसआई), मिट्टी अनुपात (सीआई) को भी मिट्टी के कटाव को संवेदनशीलता की निगरानी के लिए अध्ययन किया गया।

गांवों में सर्वेक्षण के तहत परिणामों से पता चला है कि पारंपरिक जुताई से फैलाव अनुपात (डी आर) और ईआर की औसत परिमाण क्रमशः 0.58 और 0.82 थे, और सीएमइआर 1 से कम है, जो इन मिट्टियों के कटाव प्रकृति का संकेत था। परंपरागत प्रणाली की तुलना में बिस्तर प्रणालियों के डेटा के विश्लेषण से पता चला कि औसतन, बिस्तर रोपण प्रणाली में जैविक कार्बन में 0.07-0.08 प्रतिशत की वृद्धि के रूप में थी। यह मुख्य रूप से पहले अगले दो सत्रों के लिए नये बेड रोपण प्रणाली में रिशेपिंग की वजह से मिट्टी में कम गड़बड़ी के कारण था।

मिट्टी में जैविक कार्बन में सुधार से डब्ल्यू एस -एम डब्ल्यू डी सीटी (1.57 मिमी) की तुलना में बिस्तर प्रणाली में (1.89 मिमी) वृद्धि के रूप में दर्ज की गयी। सीटी के तहत डी आर, ईआर और सीआर 0.66 से 0.52 और 4.25 और बिस्तर रोपण प्रणाली के तहत मे 0.42, 0.28 और 2.38 की कमी इन मिट्टियों में कटाव की प्रवृत्ति का संकेत दिया। इसी तरह सीएमइआर और एसआई सीटी के तहत 0.75 और 20.2 एस आइ रोपण के तहत 1.1 और 34 की वृद्धि मिट्टी संरचनात्मक हालत में सुधार का संकेत दिया। सीटी एवं जीटी मिट्टी डेटा की तुलना बी.डी. और पीआर में कमी के रूप में जैविक कार्बन एडब्ल्यूसी में सुधार को दिखाया। मिट्टी में सीटी की तुलना में जैविक कार्बन में बेहतरी के रूप में सीटी (मिमी) की तुलना में वृद्धि हुई। शून्य जुताई के तहत सीआर डी आर, ईआर और सीआर की कमी सुधार का संकेत देते हैं। संक्षेप में इस प्रकार यह निष्कर्ष निकाला गया कि संसाधन संरक्षण प्रौद्योगिकियां मिट्टी में कार्बन सुधार और मिट्टी कटाव के लिए प्रतिरोधी हैं।

हरियाणा क्षेत्र के राय ब्लॉक की मिट्टी की उत्पादन क्षमता का आकलन करने के लिए, शारीरिक दर सूचकांक विधि का इस्तेमाल किया गया। परिणाम से पता चला है कि सतह की मिट्टी में 60 प्रतिशत और उप सतह की मिट्टी में 0.45 प्रतिशत कार्बनिक पदार्थ में कमी थी। 50 प्रतिशत उप सतह मिट्टी जमी और लगभग 60 प्रतिशत

क्षेत्र इष्टतम सीमा (1–3 सेमी/घंटा) पायी गयी जो हार्ड पैन को सन्दर्भित करती है। उपसतह की ए डब्ल्यू सी जो केवल 32 प्रतिशत क्षेत्र में इष्टतम सीमा की उपस्थिति की पुष्टि को सन्दर्भित करती है। इस क्षेत्र के पीआई की संगणना ने संकेत दिया कि क्षेत्र की मध्यम उत्पादन (0.5 –0.6 पीआई के बीच सीमा) क्षमता 50–60 प्रतिशत थी। और इस क्षेत्र के बाकी क्षेत्रों की उत्पादन क्षमता बहुत कम पायी गयी।

डीआर और ईआर के रूप में संरचनात्मक सूचकांक का निर्धारण दिखाया कि क्षेत्र के 50 प्रतिशत से अधिक के क्षेत्रों में कटाव का खतरा था। अलग कटाव सूचकांक और फसल की उपज के बीच सहसंबंध महत्वपूर्ण थे और विश्लेषण ने संकेत दिया कि फैलाव अनुपात, कटाव अनुपात और मिट्टी अनुपात, गेहूं अनाज की उपज के लिए नकारात्मक रूप से सहसंबद्धित थे। इस प्रकार ऊपर दिए गए परिणाम इसकी पुष्टि करते हैं कि इन मिट्टीयों की खराब संरचनात्मक हालत के कारण पैदावार कम पायी गयी।

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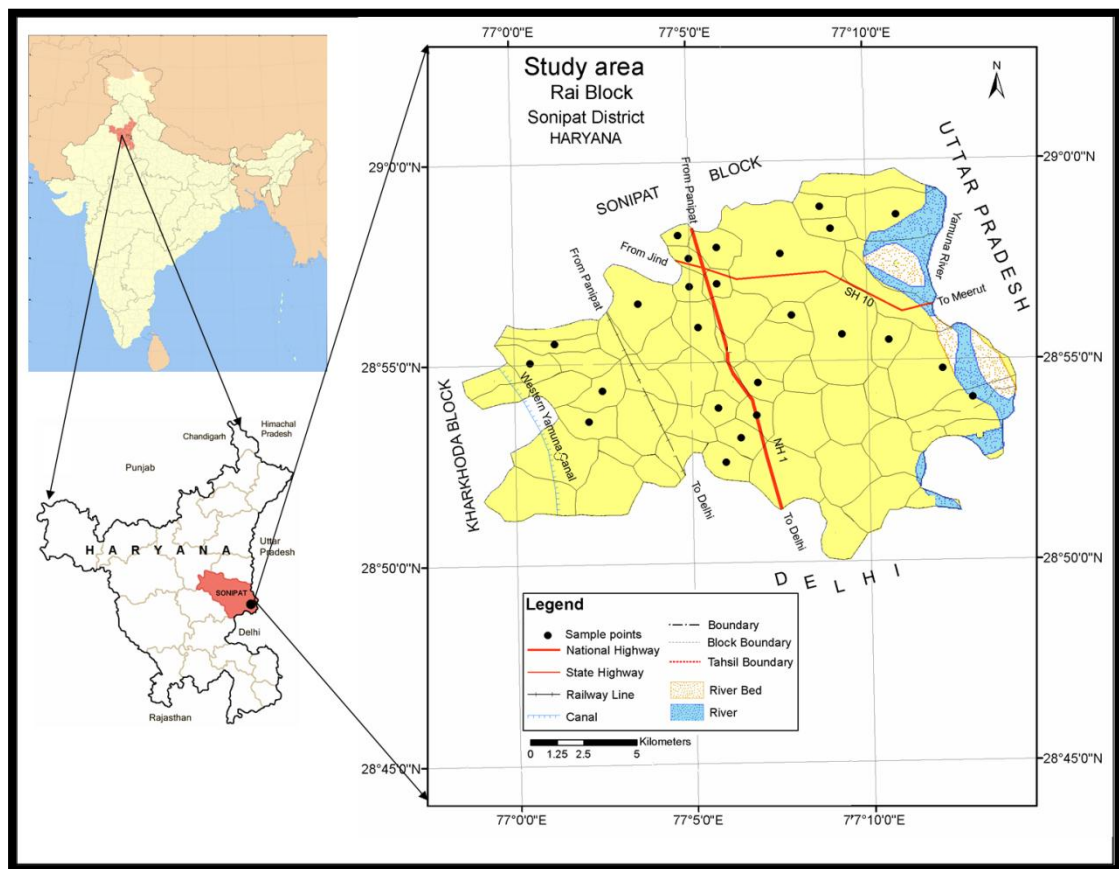


Fig. 3.1 Map of Rai block and sampling sites

Table 4.1 Methods used for studying important soil properties

Parameter	Method
Texture analysis	International Pipette method
Bulk density	Core method by Blake and Hartge (1986)
Saturated hydraulic conductivity in field and lab	Guelph permeameter (In-situ) and constant head permeameter (lab)
Soil water retention at FC and PWP	Pressure plate apparatus (Klute,1986)
Oxidisable soil organic carbon	Walkley and Black method (1934)
pH	pH meter
EC	EC meter

Table 4.2 Descriptive Statistics of soil samples collected in the farmers' fields

	0-15 cm				15-30 cm			
	Mean	Minimum	Maximum	Std. Dev.	Mean	Minimum	Maximum	Std. Dev.
Clay%	23.64	12.00	36.00	7.17	18.82	9.60	33.60	6.52
Sand%	57.88	41.60	76.80	8.32	17.86	41.60	80.0	7.76
Silt%	18.49	4.80	35.20	8.46	63.33	4.80	35.20	9.91
K _{fs} (cm/h)	13.26	1.75	49.11	13.04	-	-	-	-
pH	8.04	7.65	8.38	0.18	8.04	7.65	8.44	0.18
EC(dS/m)	3.39	1.70	6.80	1.24	3.46	1.60	5.80	1.35
OC %	0.45	0.23	0.71	0.20	0.42	0.24	0.62	0.13
BD (Mg m ⁻³)	1.44	1.25	1.70	0.11	1.46	1.28	1.60	0.10
K _s (cm/h)	0.47	0.15	1.91	0.50	0.47	0.19	1.22	0.24
FC (%)	25.68	21.48	30.00	2.22	22.54	19.63	31.75	2.75
PWP (%)	11.18	8.36	16.70	2.13	10.89	7.99	13.92	1.76
AWC %	14.50	9.81	19.58	2.40	11.65	5.91	19.59	3.24
NCP %	11.15	6.44	18.45	3.45	11.45	4.97	20.11	6.18
Saturation %	36.83	30.66	46.61	3.62	33.51	27.01	49.85	5.46
DS-MWD	5.15	4.68	5.94	0.33	5.02	4.47	5.71	0.35
WS-MWD	1.44	0.52	2.17	0.44	1.49	1.03	1.91	0.22
Dispersion ratio (DR)	0.58	0.14	0.97	0.26	0.42	0.07	0.83	0.25
Clay moisture equivalent ratio (CMER)	0.92	0.36	1.82	0.38	0.87	0.36	1.82	0.34
Erosion ratio (ER)	0.82	0.11	1.94	0.55	0.56	0.06	1.94	0.47
Clay ratio (CR)	4.58	1.78	9.42	2.12	4.46	1.78	9.42	1.75

Table 4.3 Correlation among various erosion/aggregation indices

	DS-MWD (mm)	WS-MWD (mm)	DR	CMER	ER	CR	CMWD (mm)	SI (%)
DS-MWD (mm)	1.00	0.25	-0.08	0.27	-0.22	-0.32	0.43	0.12
WS-MWD (mm)	0.25	1.00	-0.21	0.01	-0.11	0.06	* -0.73	-0.04
DR	-0.08	-0.21	1.00	* -0.56	* 0.83	* 0.62	0.21	* -0.93
CMER	0.27	0.01	* -0.56	1.00	-0.84	* -0.89	0.13	* 0.62
ER	-0.22	-0.10	* 0.83	* -0.84	1.00	* 0.92	0.01	* -0.83
CR	-0.32	0.06	* 0.62	* -0.89	0.92	1.00	-0.21	* -0.69
CMWD (mm)	0.43	* -0.73	0.21	0.13	0.01	-0.21	1.00	0.07
SI (%)	0.12	-0.04	* -0.93	* 0.62	* -0.83	* -0.69	0.07	1.00

Table 4.4 Linear multi regression equation relating wet sieving mean weight diameter (WS-MWD) with other basic soil parameters

		Coefficient	St. error	T-value	R²
WS-MWD	Intercept	8.610	3.880	2.219	0.59
	pH	-0.972	0.497	* -1.957	
	EC (dS m ⁻¹)	-0.143	0.066	* -2.159	
	OC %	0.520	0.509	1.022	
	BD (Mg m ⁻³)	-0.530	1.253	-0.423	
	AWC %	0.063	0.039	1.600	
	NCP %	-0.115	0.039	* -2.917	
	Clay %	0.035	0.017	* 2.086	
	Sand %	0.021	0.012	1.729	

Table 4.5 Linear multi regression equation showing Dispersion ratio (DR) as a function of basic soil parameters

		Coefficient	St. error	T-value	R²
DR	Intercept	-0.496	2.704	-0.184	* 0.43
	pH	-0.007	0.006	-1.271	
	EC (dS m ⁻¹)	-0.705	0.386	-1.828	
	OC %	0.083	0.048	1.717	
	BD (Mg m ⁻³)	-0.074	0.282	* -0.263	
	AWC	1.652	0.821	* 2.013	
	NCP	0.070	0.028	* 2.482	
	Clay %	-0.023	0.012	* -2.006	
	Sand %	0.019	0.009	* 2.227	

Table 4.6 Linear multi regression equation showing clay moisture equivalent ratio (CMER) as a function of basic soil parameters

		Coefficient	St. error	T-value	R²
CMER	Intercept	-7.089	2.695	-2.631	0.77
	K _{fs} (cm h ⁻¹)	0.018	0.006	* 3.269	
	pH	1.492	0.382	* 3.911	
	EC (dS m ⁻¹)	-0.095	0.047	* -2.001	
	OC %	-0.402	0.361	-1.115	
	BD (Mg m ⁻³)	1.067	0.928	1.150	
	AWC %	0.023	0.031	0.748	
	NCP %	0.088	0.035	* 2.505	
	Saturation %	-0.116	0.035	* -3.332	
	Clay %	-0.022	0.013	-1.736	
	Sand %	-0.031	0.009	* -3.541	

Table 4.7 Linear multi regression equation showing clay ratio (CR) as a function of basic soil parameters

		Coefficient	St. error	T-value	R²
CR	Intercept	47.302	22.812	2.074	0.55
	K _{fs} (cm h ⁻¹)	0.095	0.044	* 2.184	
	pH	-8.176	2.992	* -2.732	
	EC (dS m ⁻¹)	0.517	0.371	1.393	
	OC %	1.264	2.828	0.447	
	BD (Mg m ⁻³)	2.759	7.280	0.379	
	AWC %	-0.111	0.245	-0.455	
	NCP %	-0.385	0.277	-1.393	
	Saturation %	0.690	0.273	* -2.528	
	Sand %	0.021	0.080	0.267	
	Silt %	-0.148	0.098	-1.505	

Table 5.1 Rating of different soil physical parameters for crop cultivation

BD (Mg m ⁻³)			K _{fs} (cm h ⁻¹)		AWRC (cm m ⁻¹)		OC (%)		NCP (%)	
Range for fine texture soils	Range for coarse texture soils	Rating	Range	Rating	Range	Rating	Range	Rating	Range	Rating
1.30-1.45	0.90	1.00	1.0-3.0	1.00	>15.0	1.00	>1.20	1.00	>15.0	0.90
1.45-1.50	1.00	0.95	0.5-1.0	0.95	12.5-15.0	0.95	0.90-1.20	0.95	12.5-15.0	1.00
1.50-1.55	1.00	0.90	0.2-0.5	0.90	10.0-12.5	0.90	0.60-0.90	0.90	10.0 -12.5	0.90
1.55-1.60	1.00	0.85	0.1-0.2	0.85	7.5-10.0	0.80	0.45-0.60	0.85	7.5-10.0	0.80
1.60-1.65	0.90	0.80	0.05-0.1	0.8	5.0-7.5	0.75	0.30-0.45	0.80	5.0-7.5	0.70
1.65-1.70	0.85	0.75	0.01-0.05	0.75	< 5.0	0.70	0.20-0.30	0.75	< 5.0	0.65
1.70-1.75	0.8	0.70	<0.01	0.70						
1.75-1.85	0.75	0.65								

Table 5.2 Correlation of different stability indices with wheat grain yield

	WS-MWD (mm)	DR	CMER	ER	CR	SI	YIELD (q ha ⁻¹)
WS-MWD (mm)	1.00	-0.21	0.01	-0.10	0.06	0.01	-0.21
DR	-0.21	1.00	-0.56	0.83	0.62	-0.96	-0.36
CMER	0.01	-0.56	1.00	-0.84	-0.89	0.59	0.32
ER	-0.10	0.83	-0.84	1.00	0.92	-0.82	* -0.47
CR	0.06	0.62	-0.89	0.92	1.00	-0.67	* -0.51
SI	0.01	-0.96	0.59	-0.82	-0.67	1.00	* 0.43
YIELD (q ha ⁻¹)	-0.21	-0.36	0.32	-0.47	-0.51	0.43	1.00



Figure 3.2 Modified bed planter 'Trifala', vegetables grown on bed and in-situ measurement of Saturated hydraulic conductivity by Guleph permeameter in farmers' fields



Figure 3.3 Zero seed drill and zero tilled field

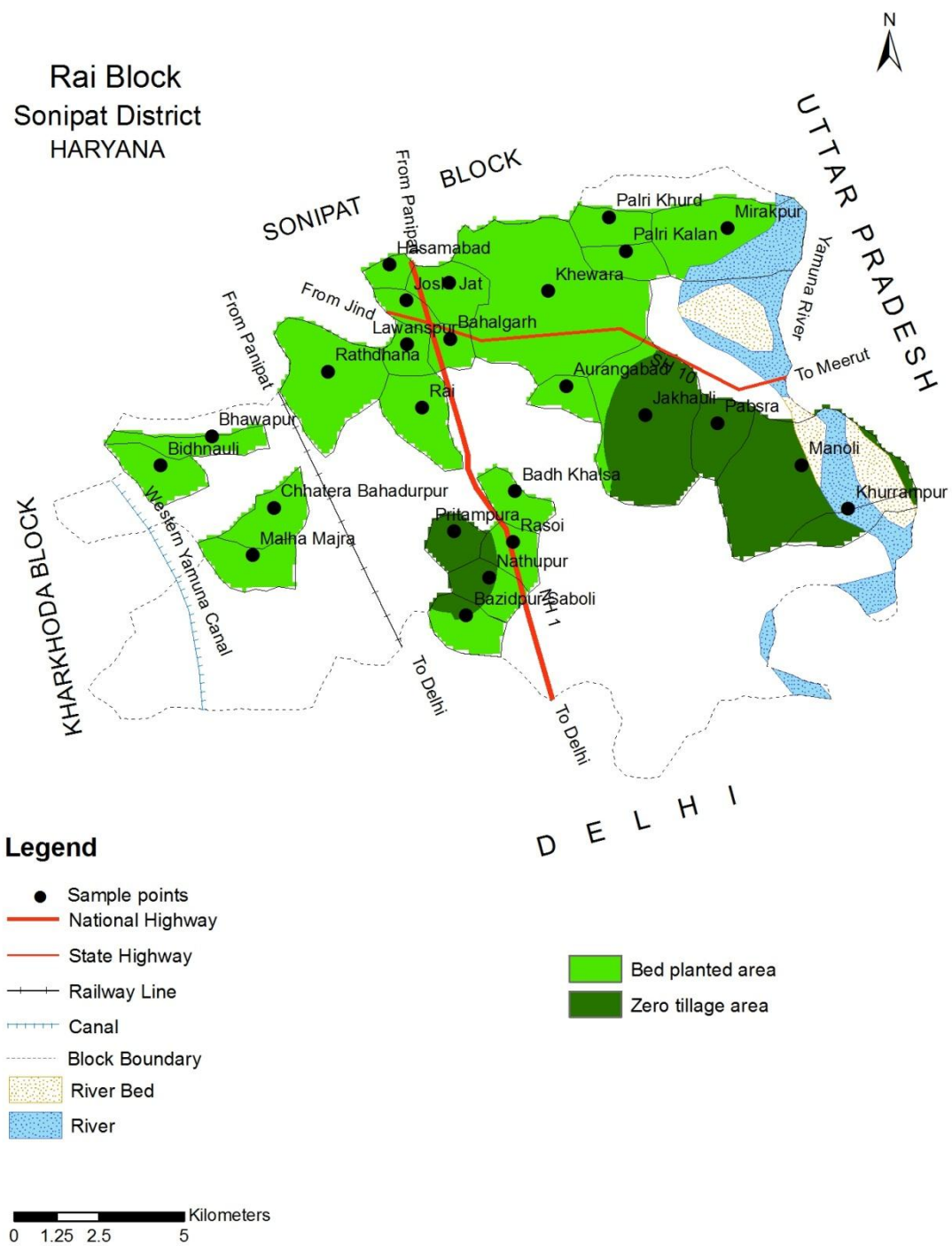


Figure 4.1 Bed planting and Zero tillage adopted areas of Rai block

Soil Texture

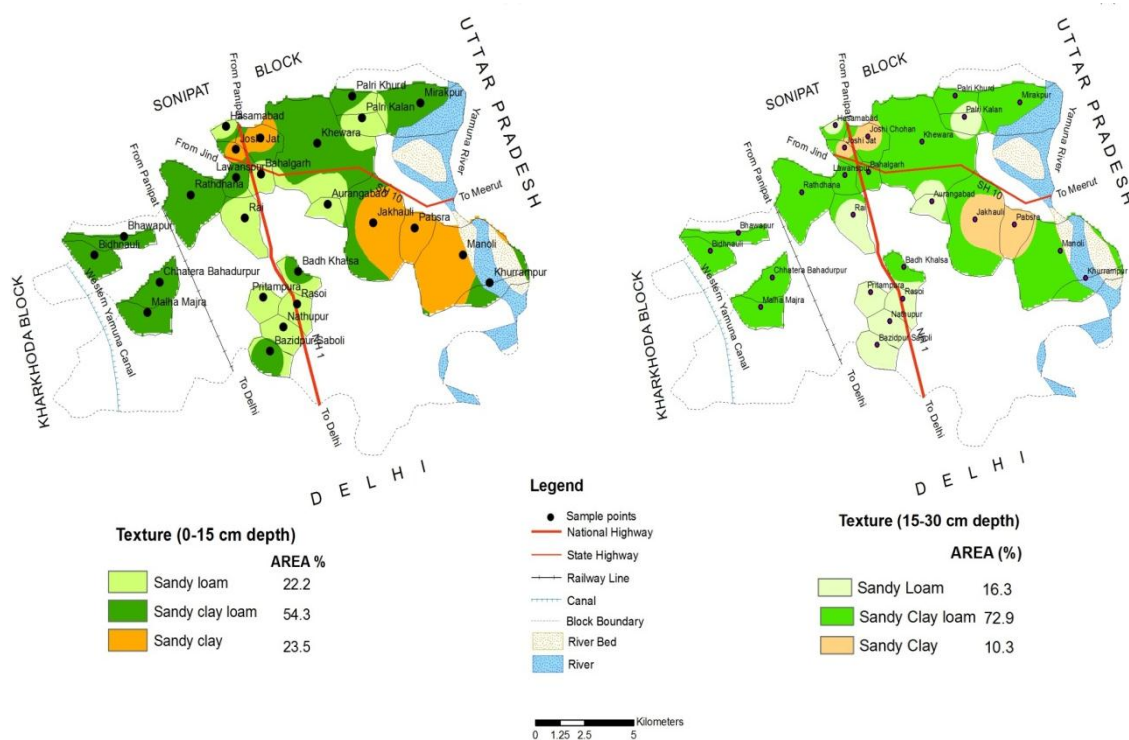
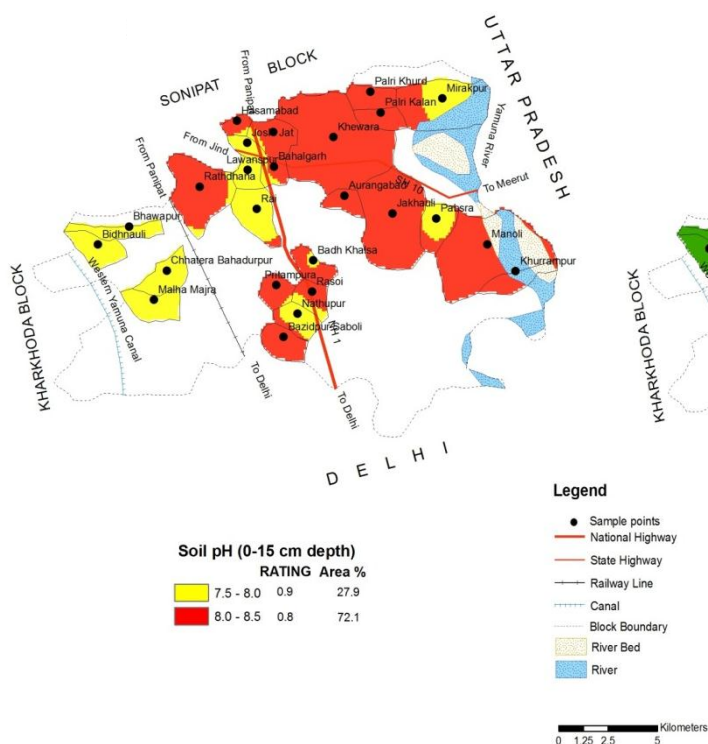


Fig. 5.1 Prediction maps of soil texture

Soil



Soil

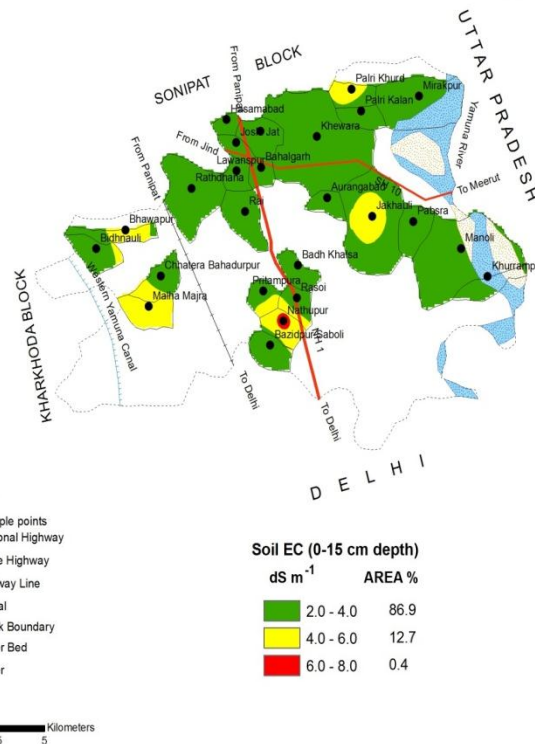


Fig. 5.2 Prediction maps of soil pH and EC

Soil OC

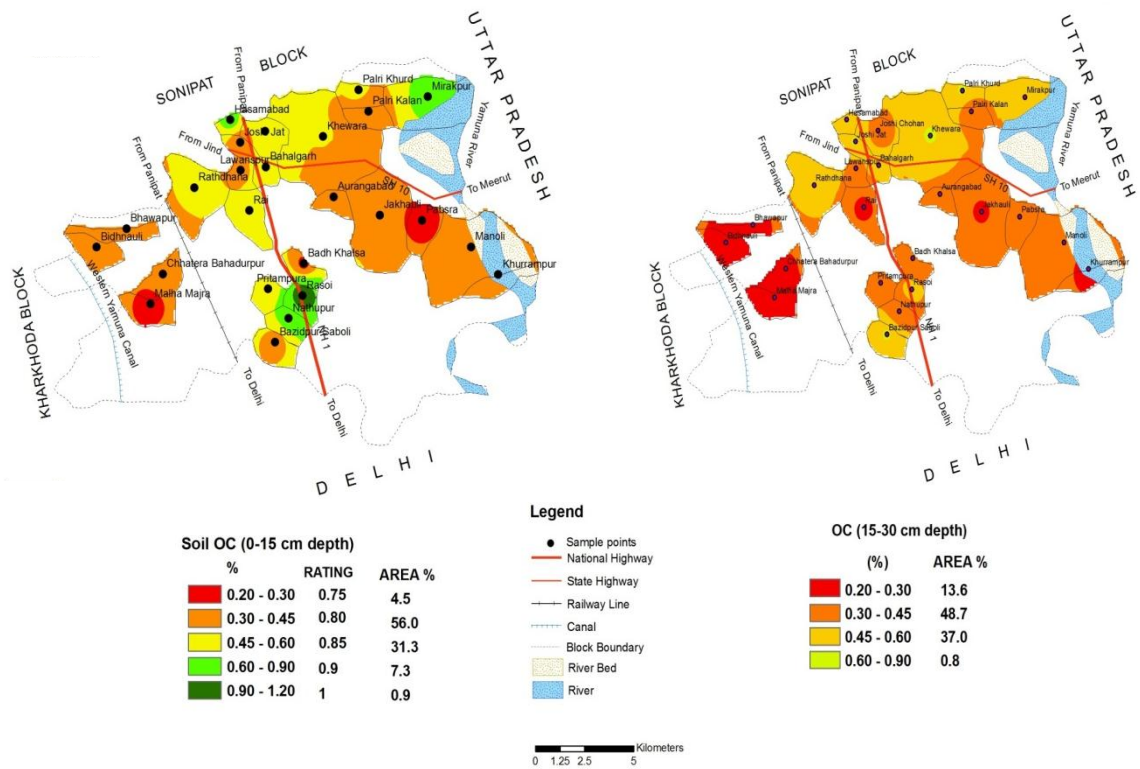


Fig.5.3 Prediction maps of soil organic carbon (OC)

Soil BD

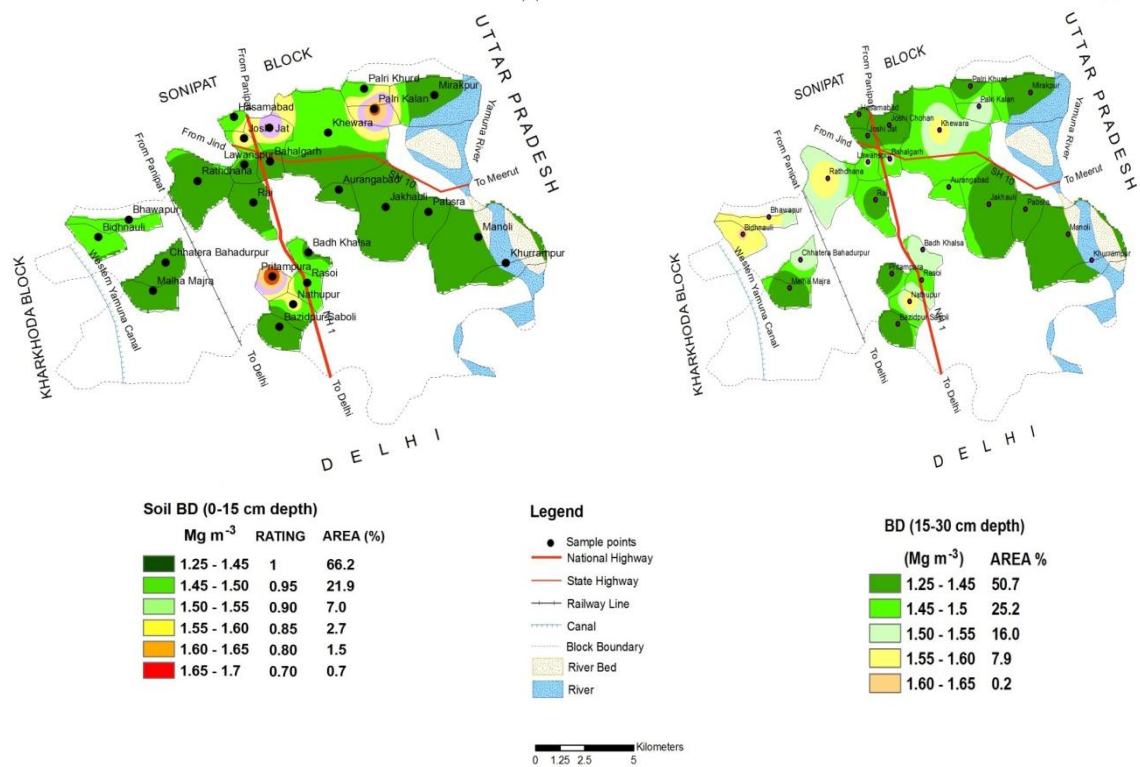


Fig. 5.4 Prediction maps of soil bulk density

Field Saturated Hydraulic Conductivity

Hydraulic Conductivity (Lab Method)

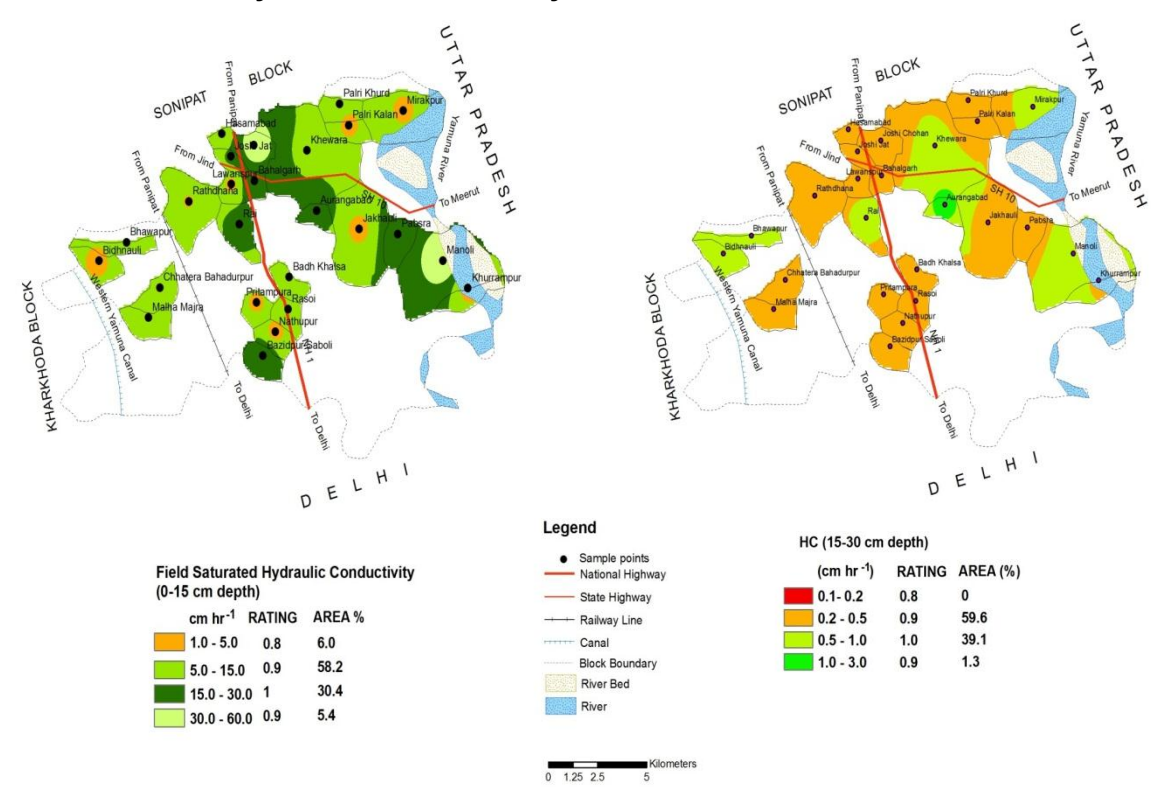


Fig. 5.5 Prediction maps of saturated hydraulic conductivity (Field and lab method)

AWC

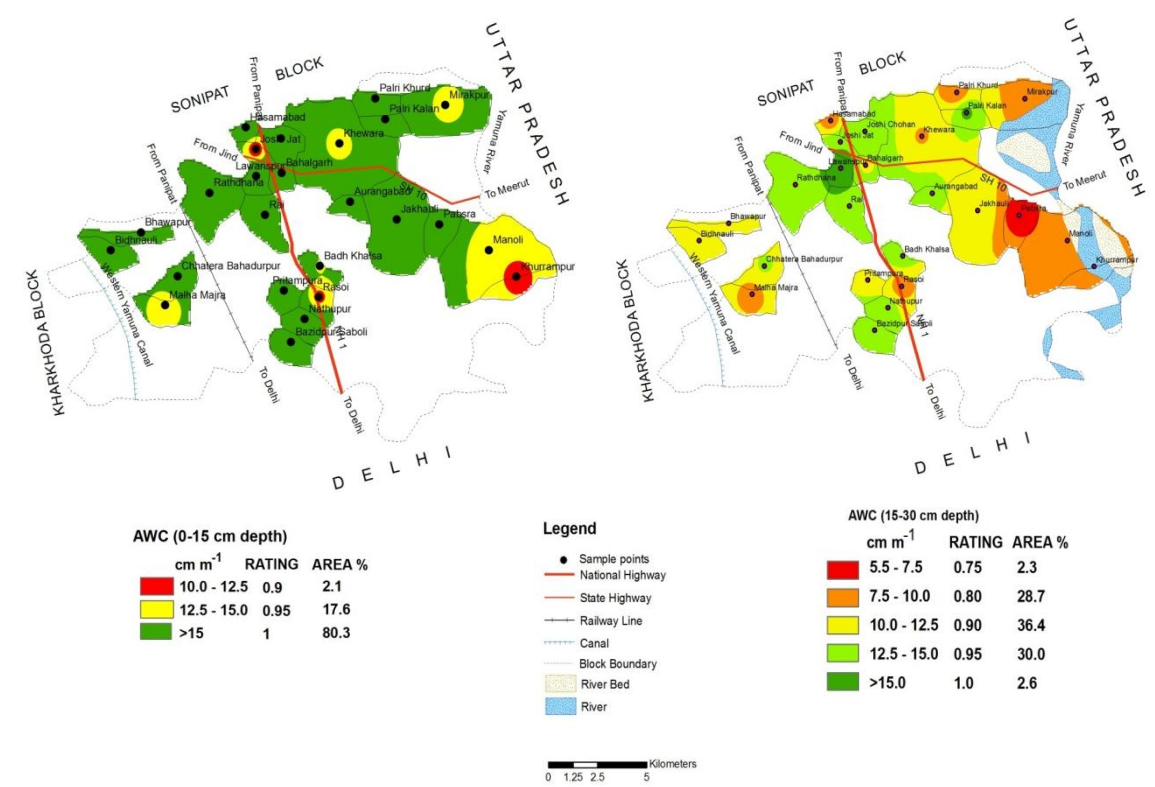


Fig. 5.6 Prediction maps of available water capacity (AWC)

NCP

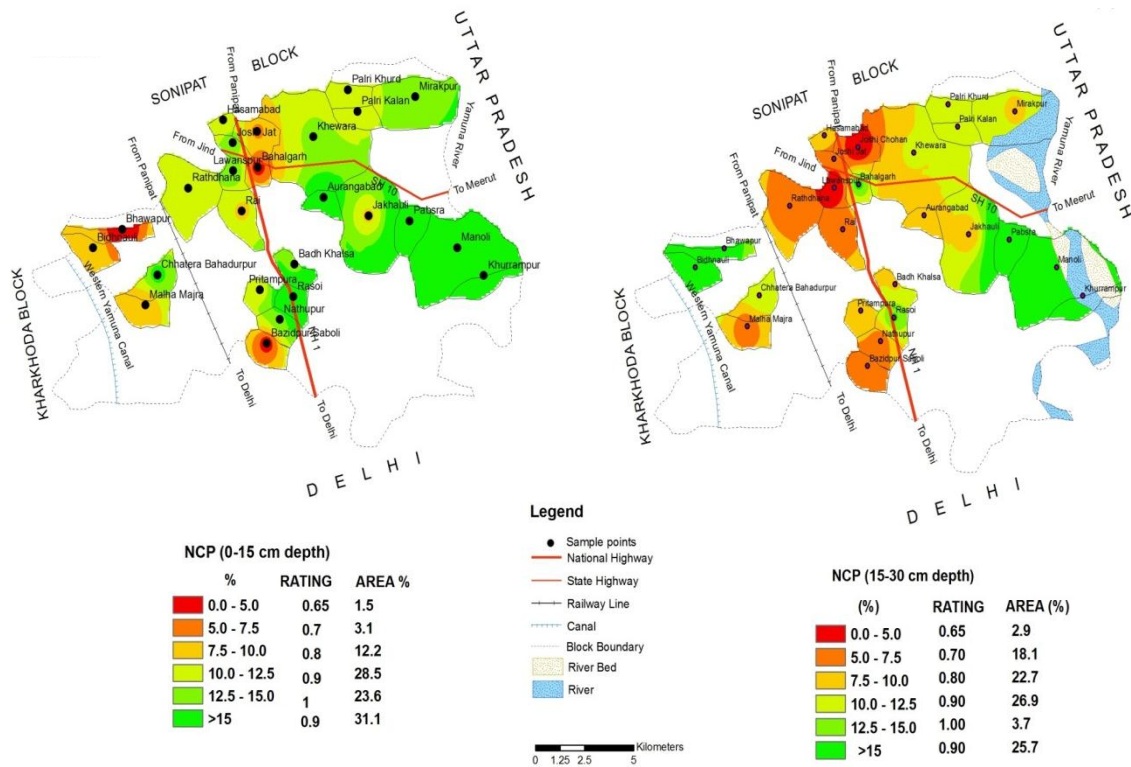


Fig.5.7 Prediction maps of non capillary porosity (NCP)

Physical Rating Index

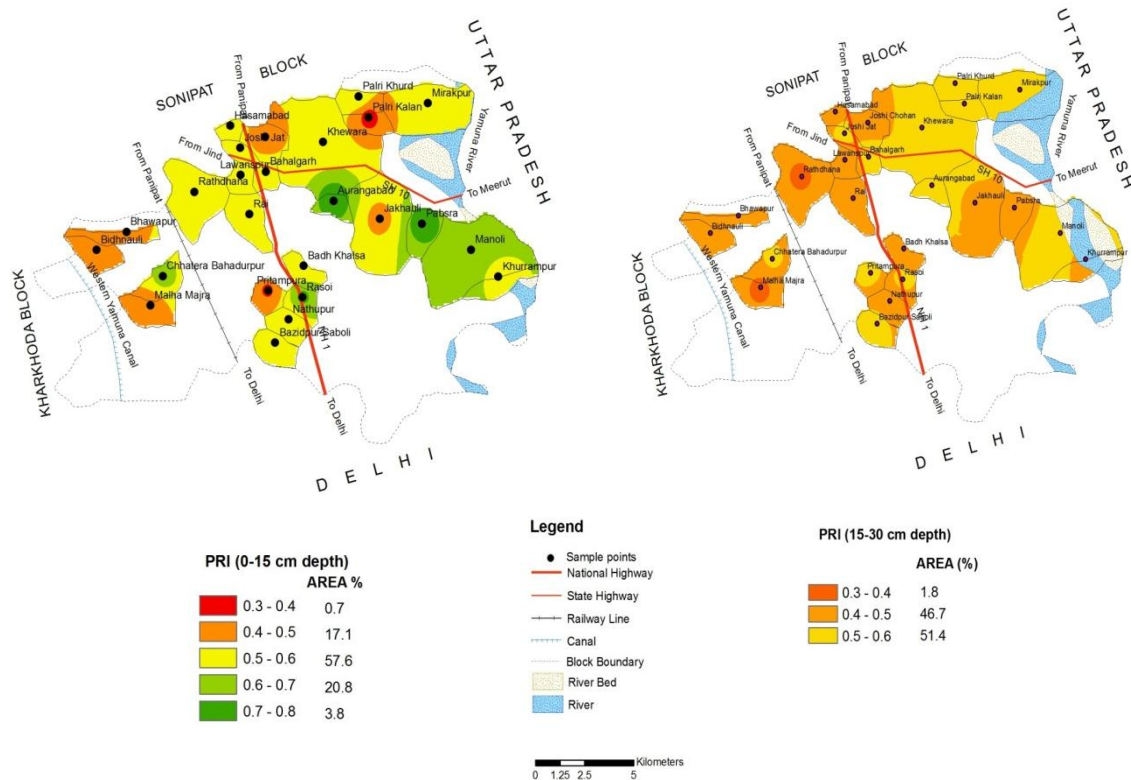


Fig. 5.8 Prediction maps of Physical rating index

Wet Sieving - MWD

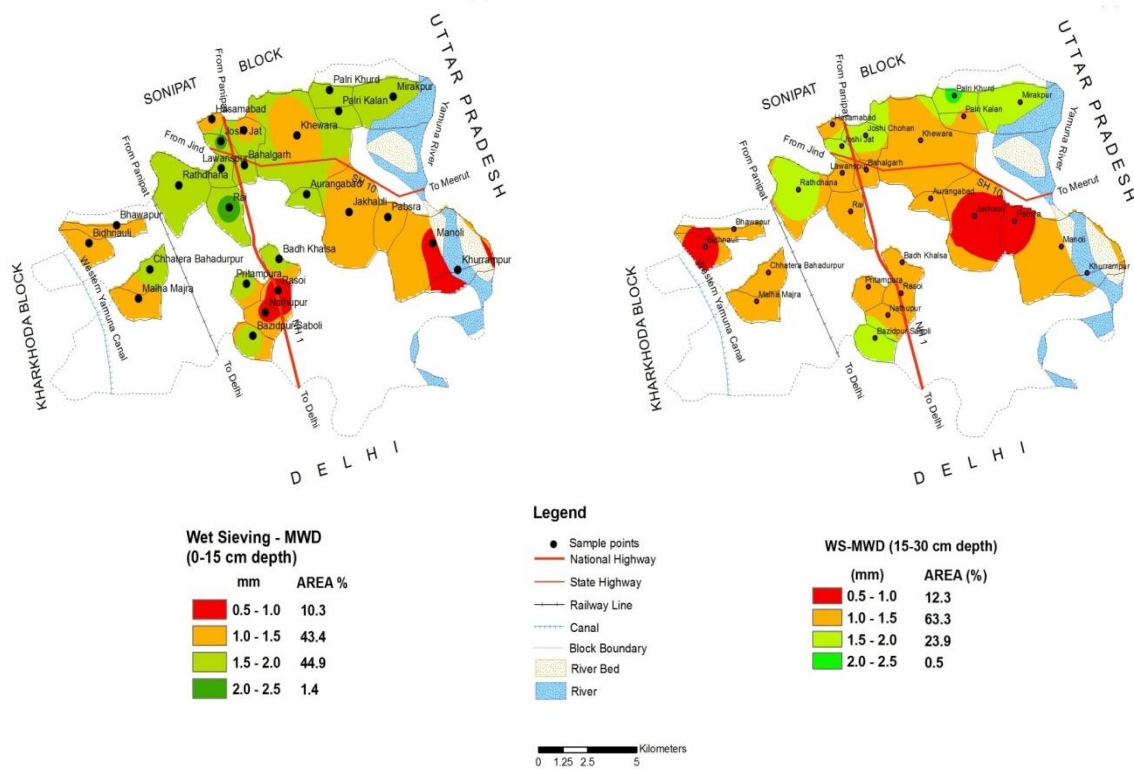
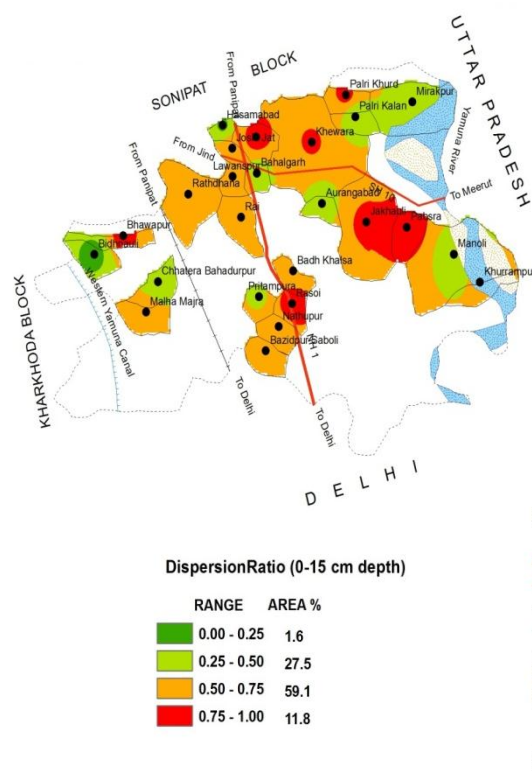


Fig. 5.9 Prediction maps of wet sieving mean weight diameter (WSMWD)

Dispersion Ratio



Erosion Ratio

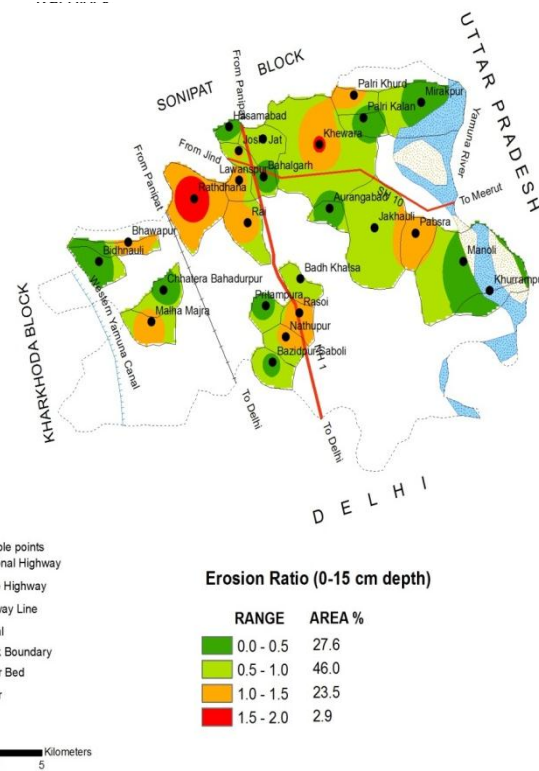


Fig. 5.10 Prediction maps of dispersion ratio (DR) and erosion ratio (ER)

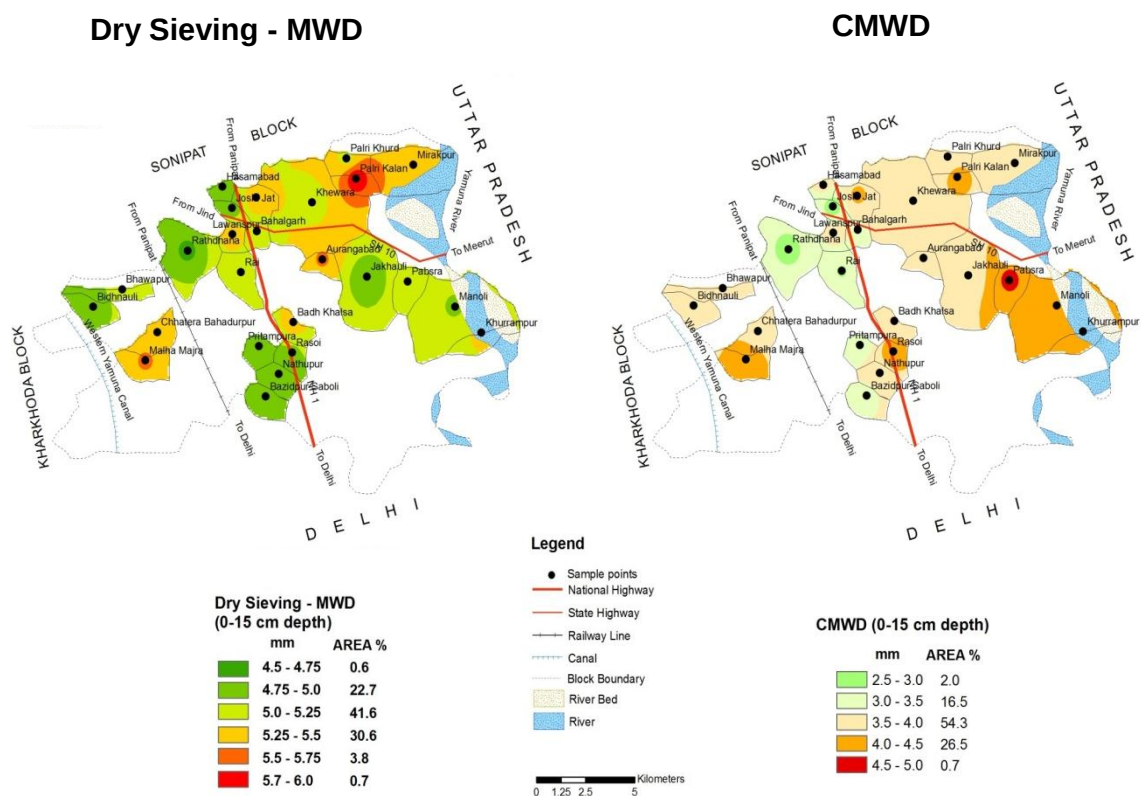


Fig. 5.11 Prediction maps of dry sieving mean weight diameter (DSMWD)

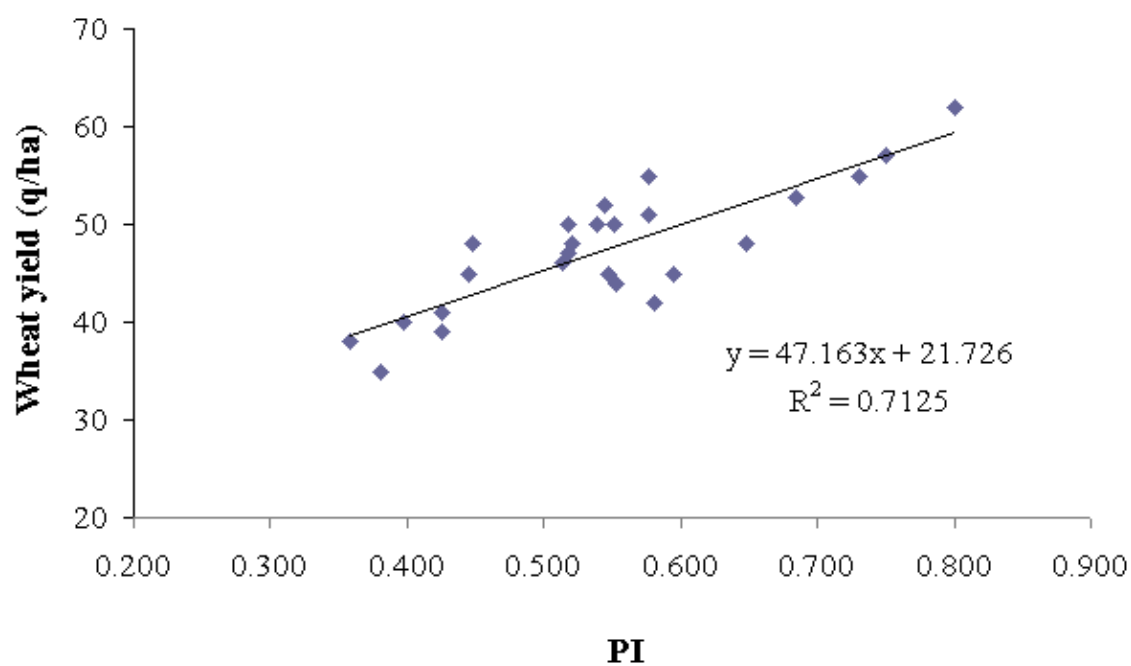


Figure: 5.12: Correlation between PI and wheat grain yield

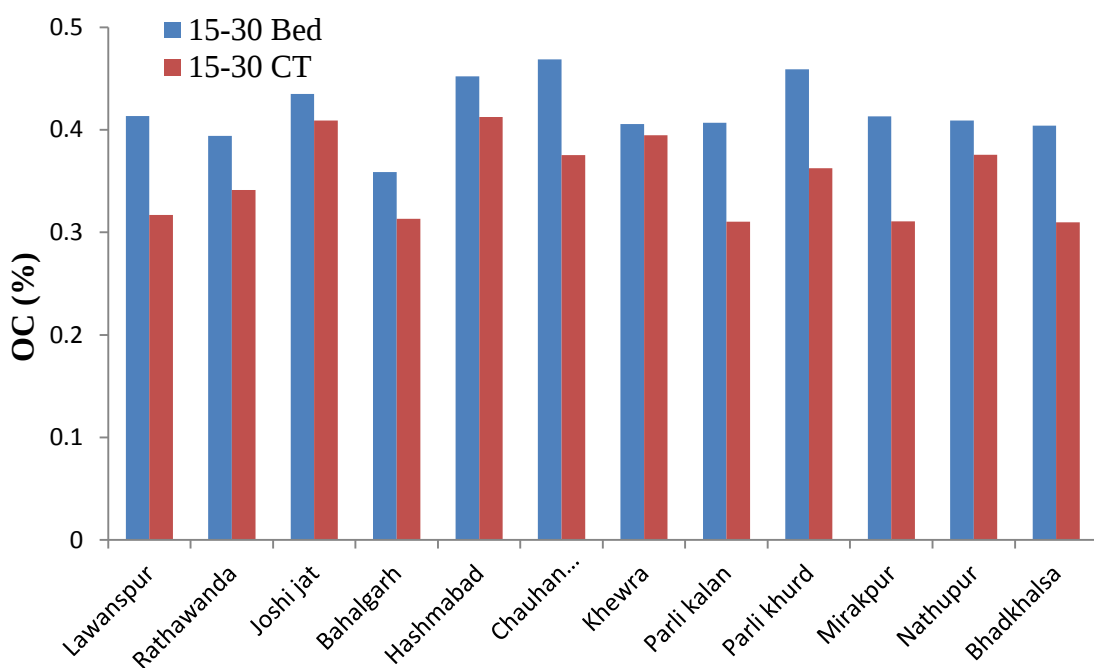
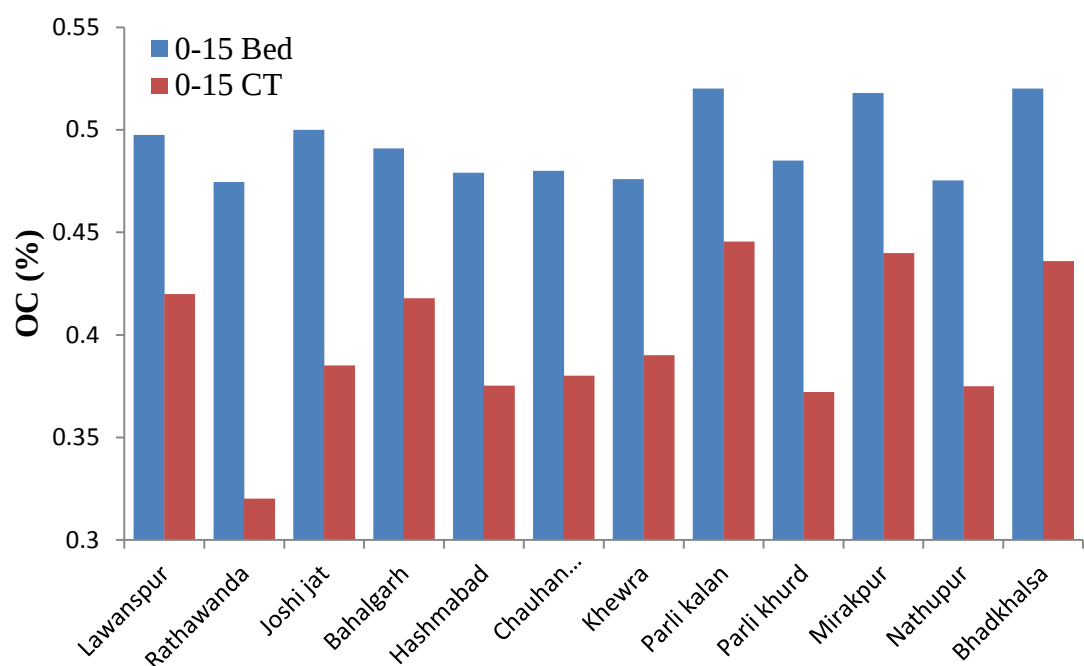


Figure 4.2 Soil organic carbon (OC) under bed and conventional system in surveyed villages

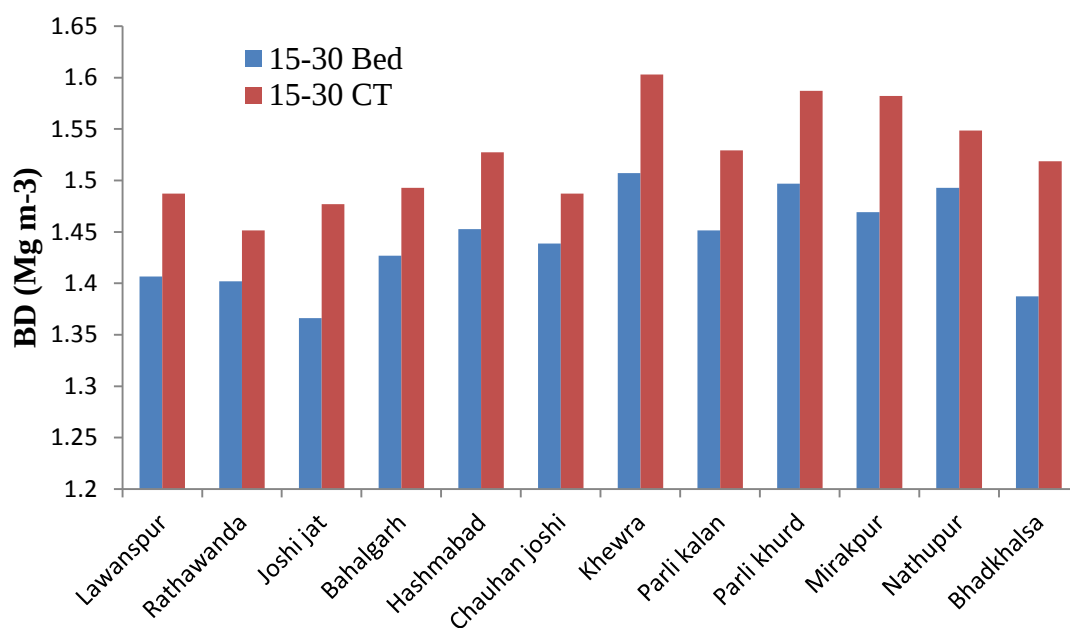
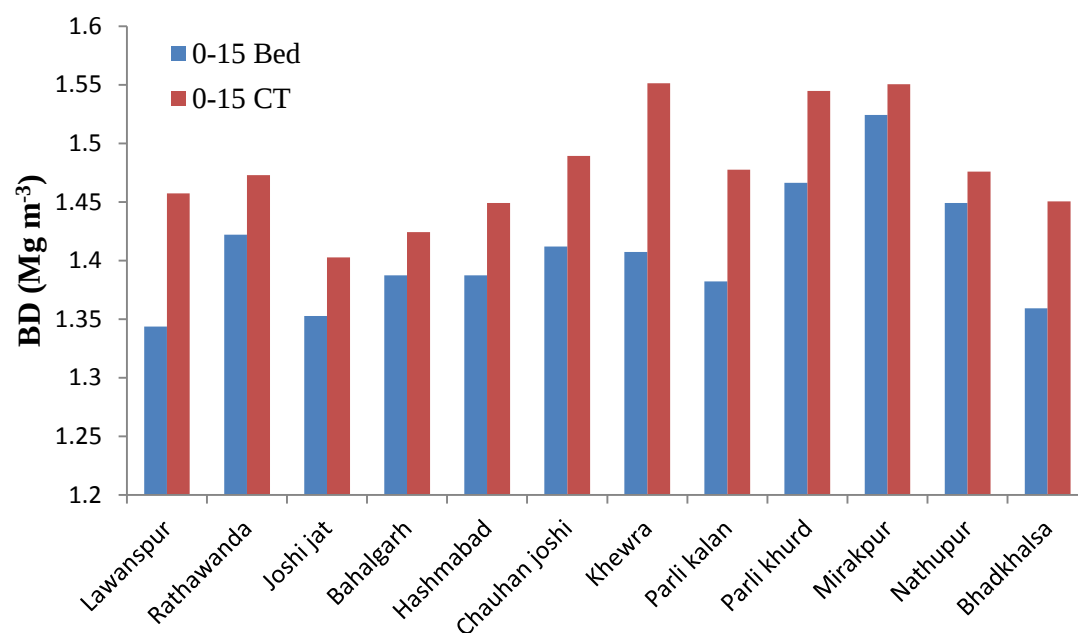


Figure 4.3 Soil bulk density (BD) under bed and conventional system in surveyed villages

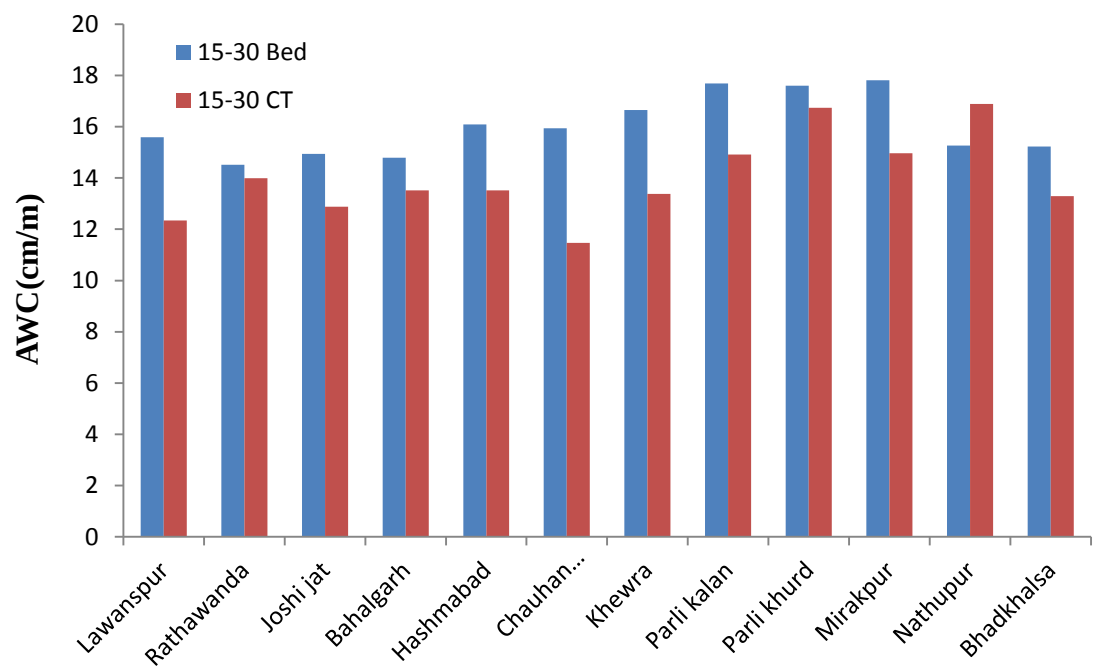
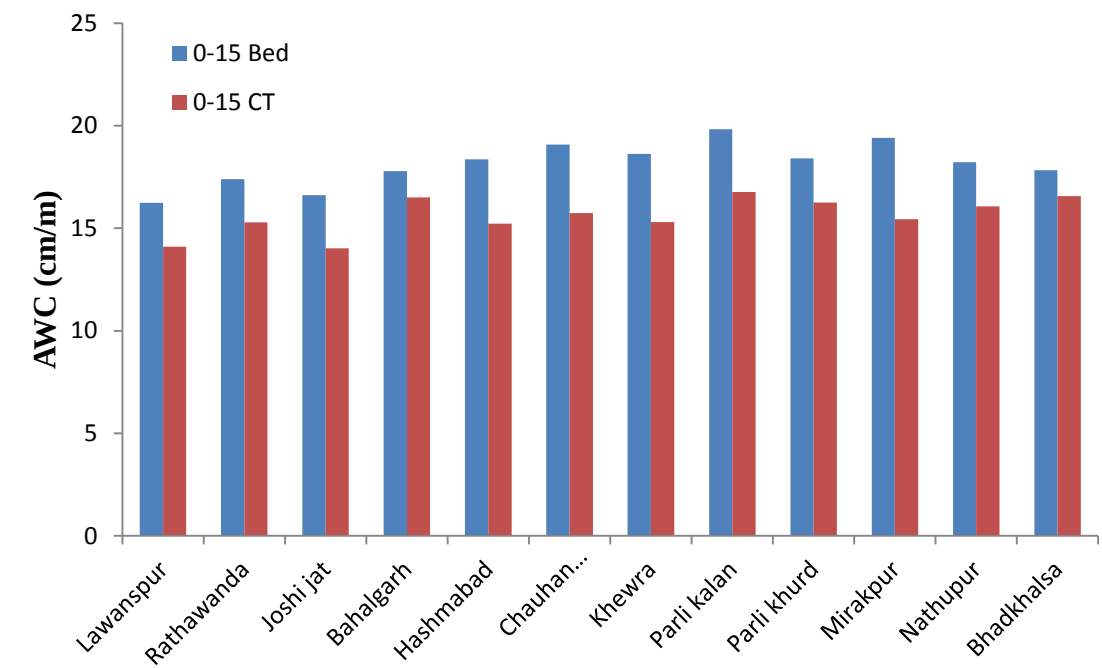


Figure 4.4 Available water capacity under bed and conventional system in surveyed villages

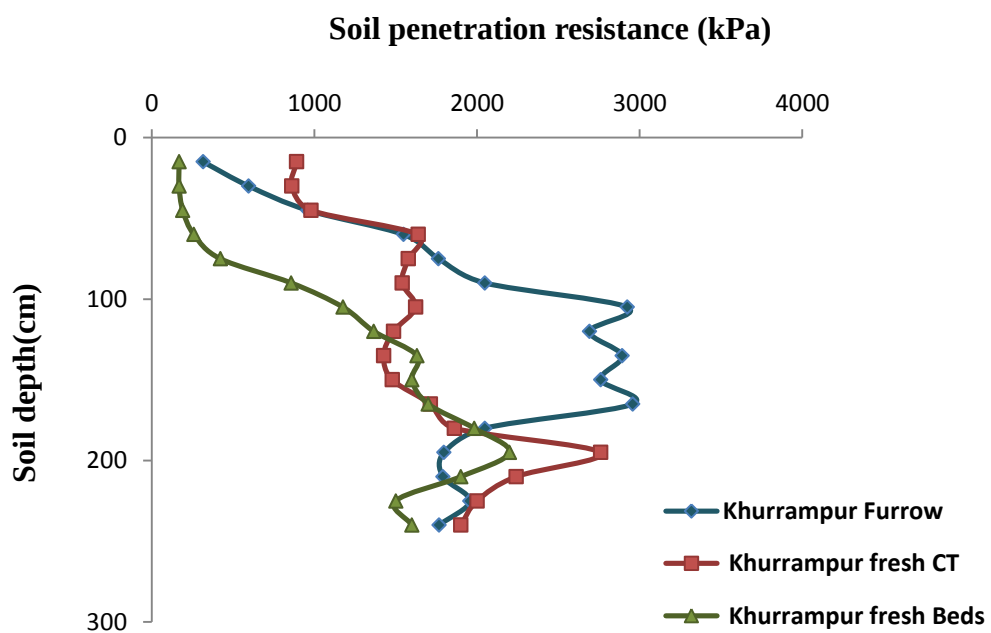
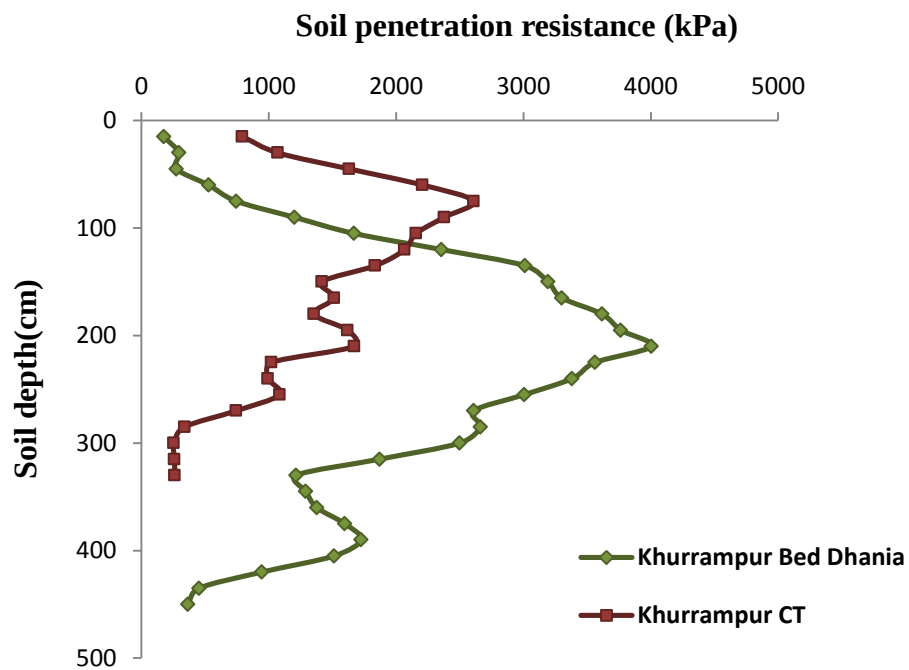


Figure 4.5 Penetration resistance of soil under bed and conventionally planted system (24.2.2012)

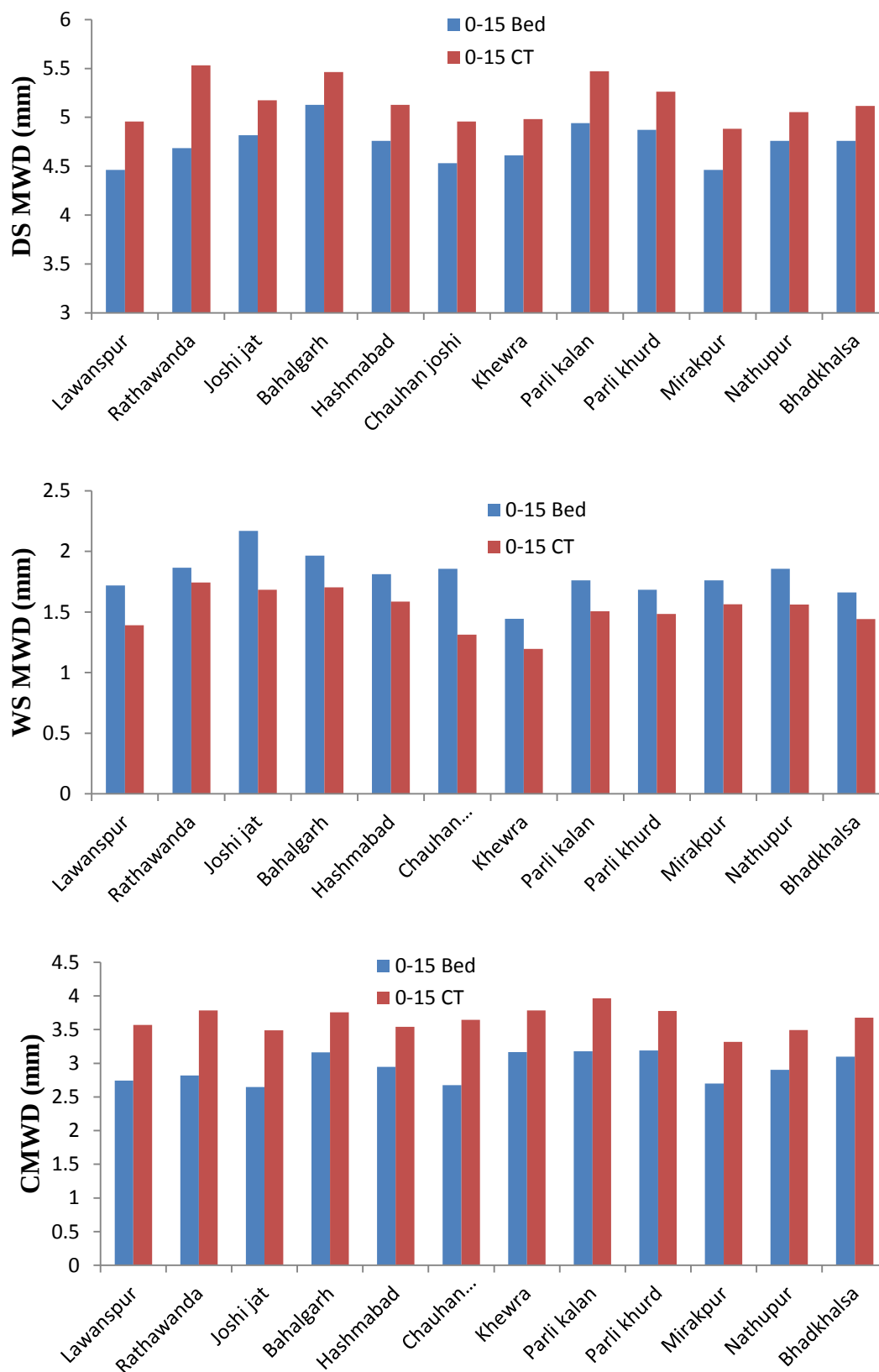


Figure 4.6 Dry sieving mean weight diameter (DS-MWD), Wet sieving mean weight diameter (WS-MWD), Change in mean weight diameter (CMWD) under bed and conventional system in surveyed villages

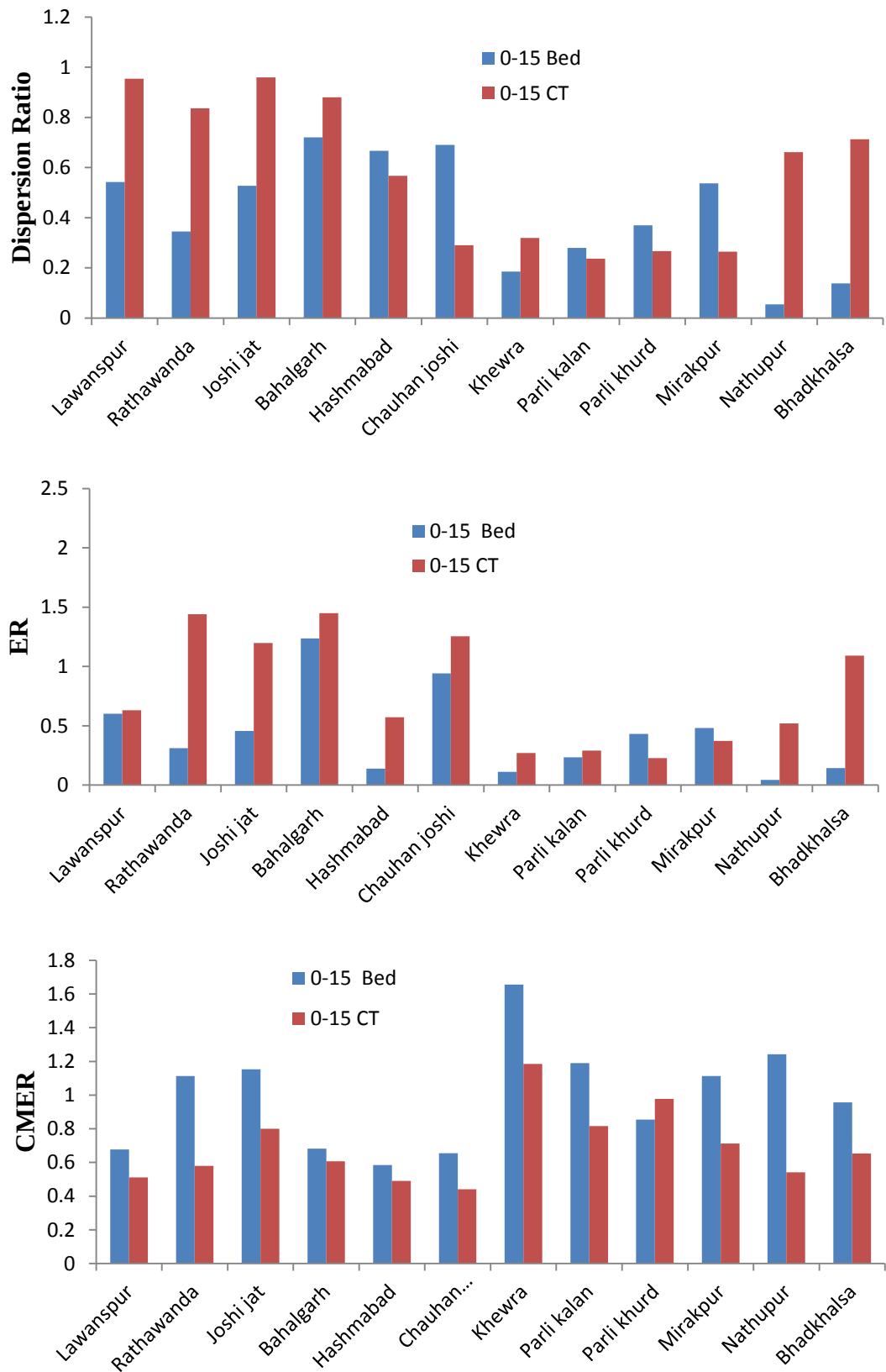


Figure 4.7 Dispersion ratio, Erosion ratio and clay moisture equivalent ratio (CMER) under bed and conventional system in surveyed villages

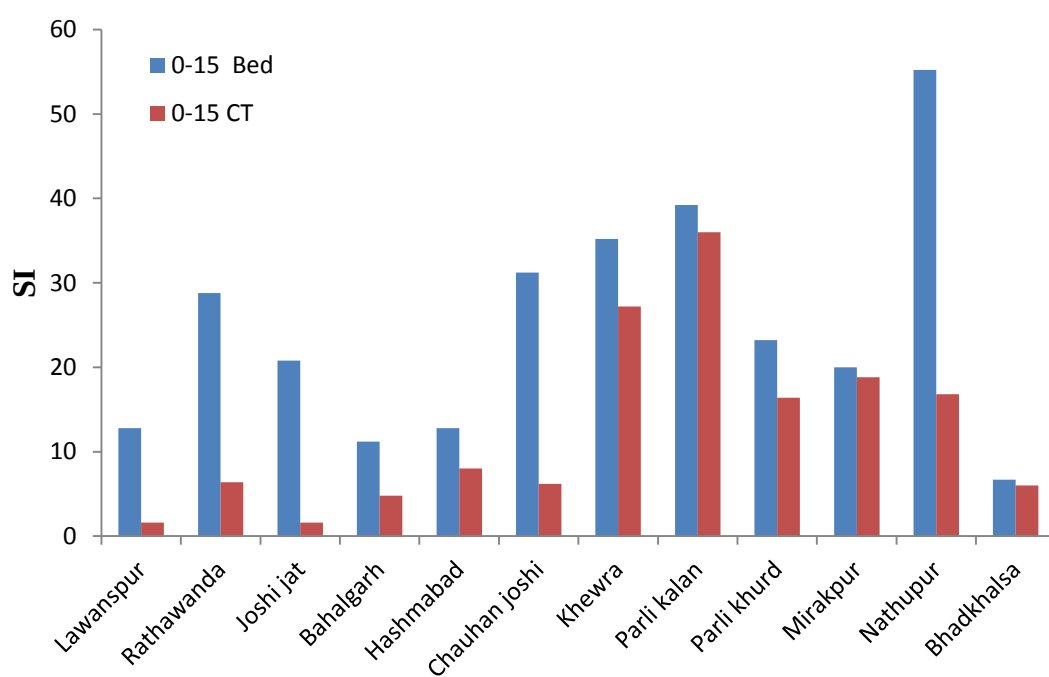
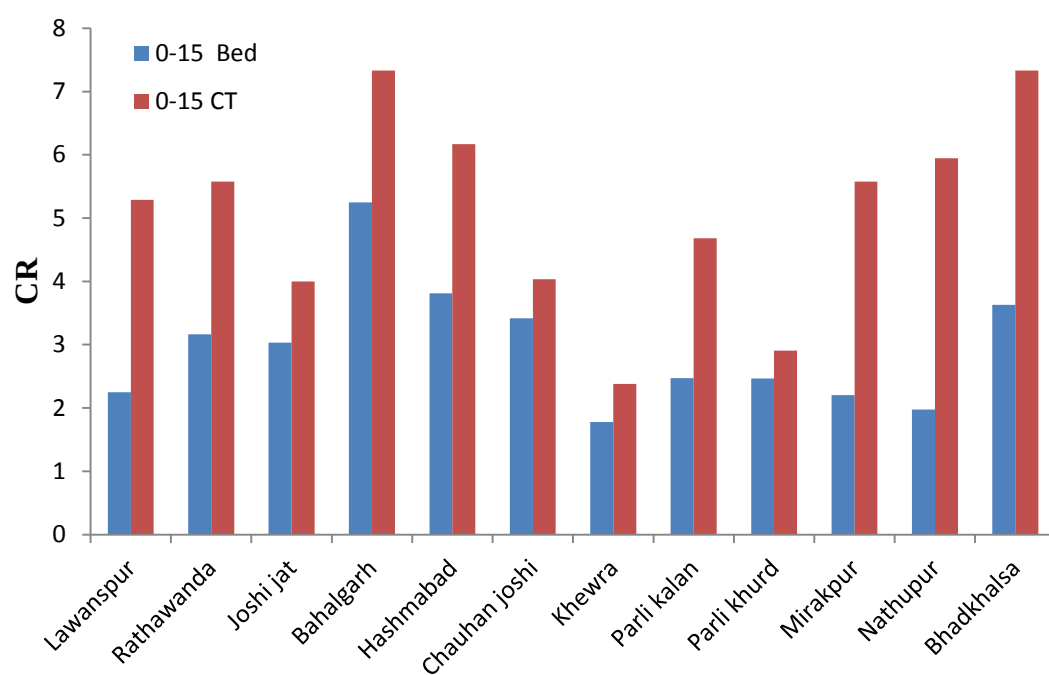


Figure 4.8 Clay ratio (CR) and Stability index (SI) under bed and conventional system in surveyed villages

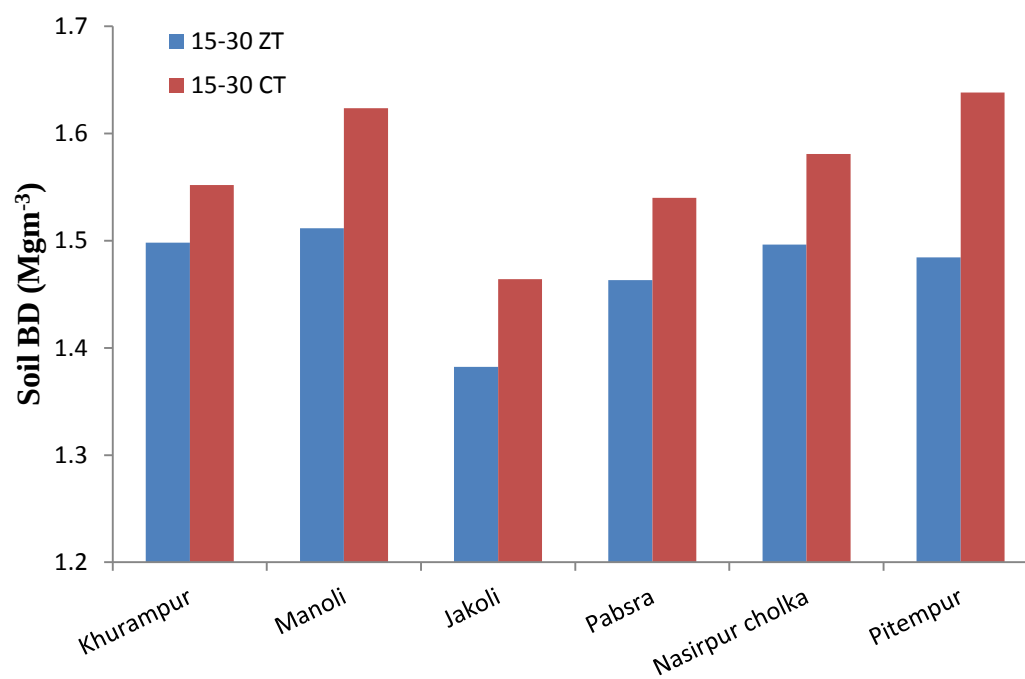
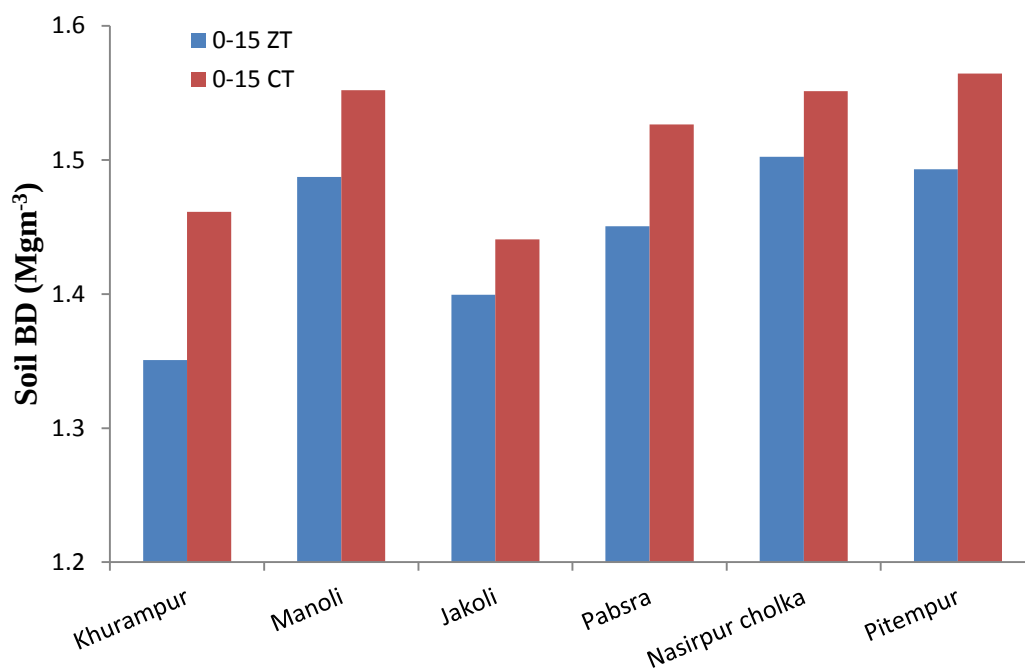


Figure 4.9 Soil bulk density (BD) under zero tillage (ZT) and conventional system (CT) in surveyed villages

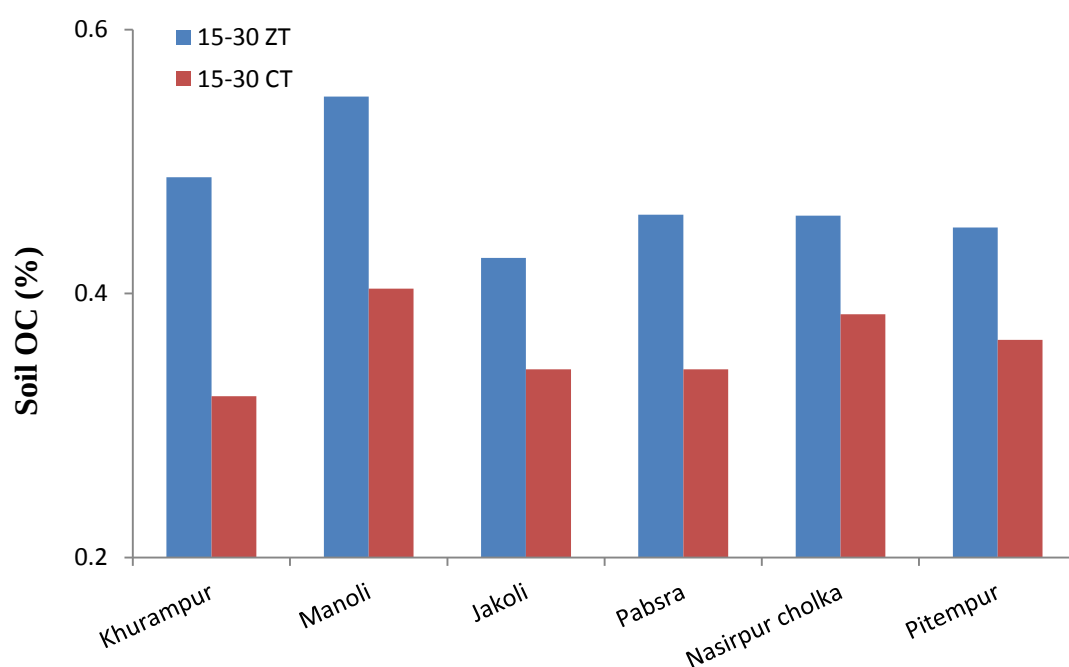
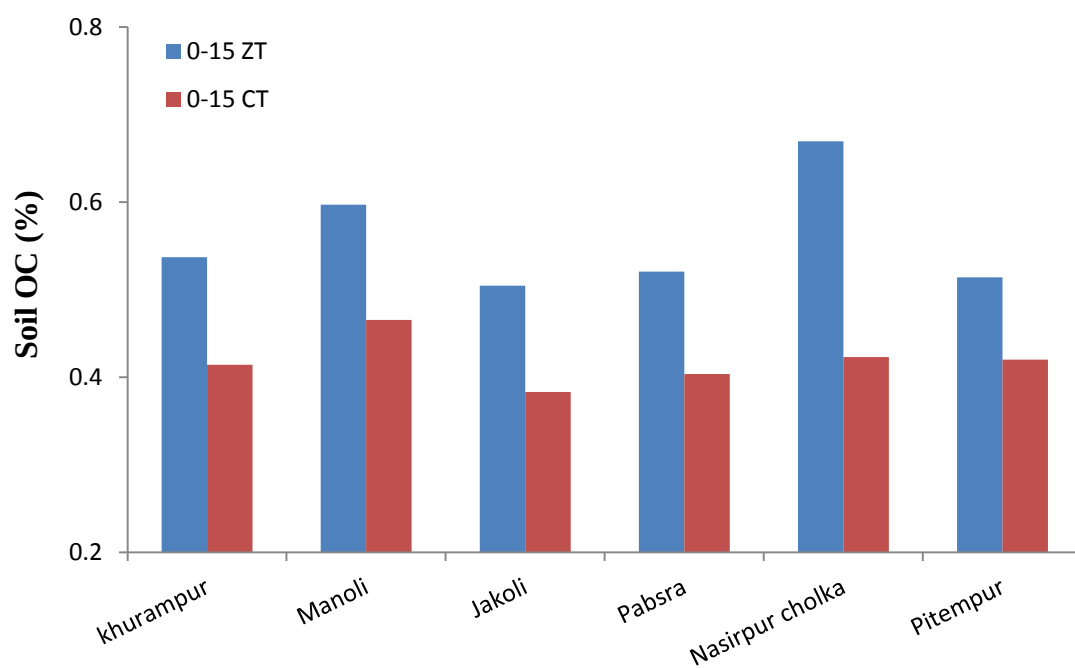


Figure 4.10 Soil organic carbon (OC) under zero tillage and conventional system in surveyed villages

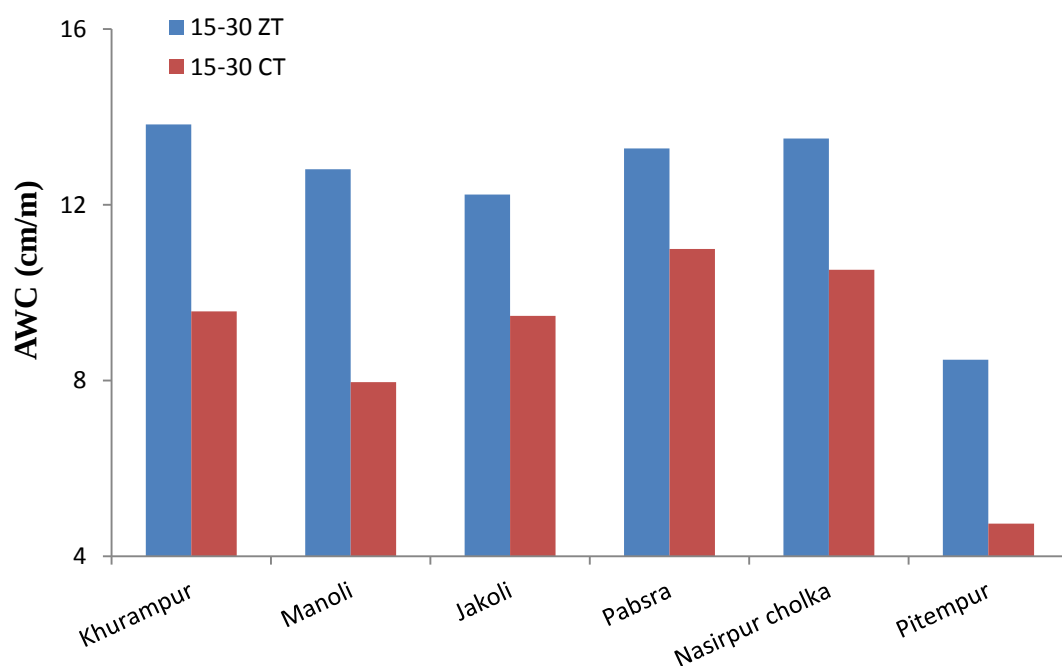
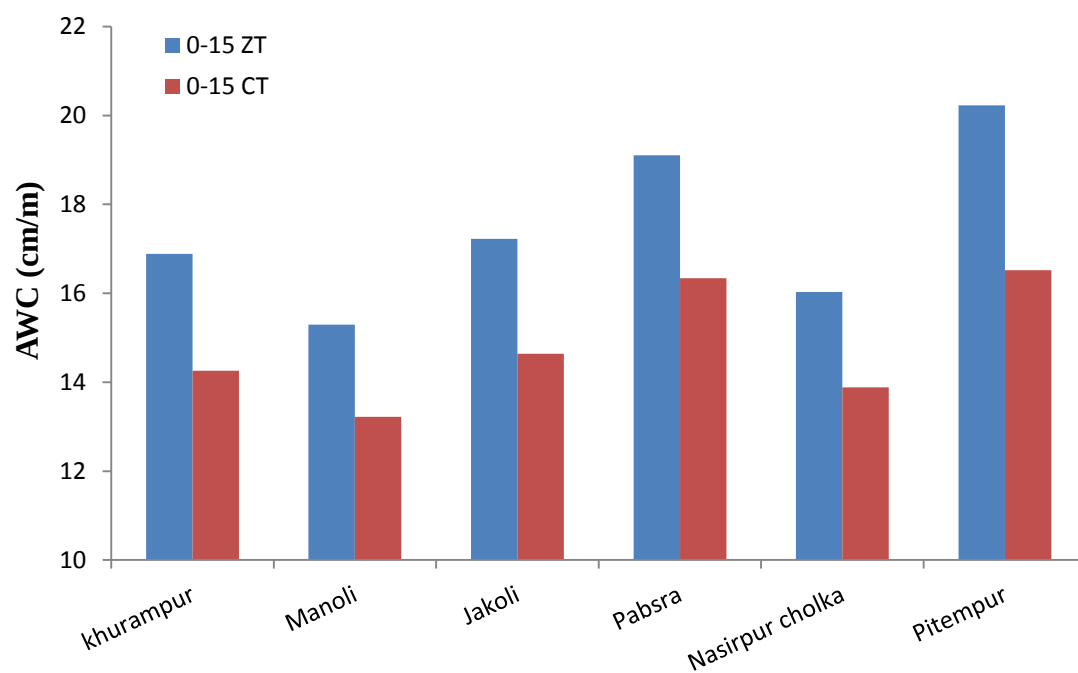


Figure 4.11 AWC under zero tillage and conventional system of surveyed sites

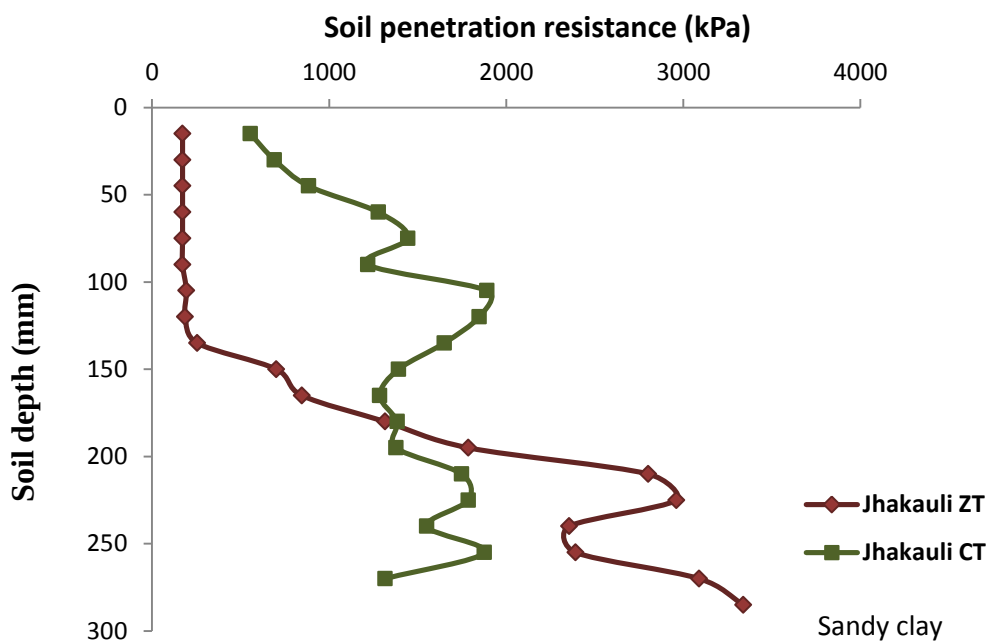
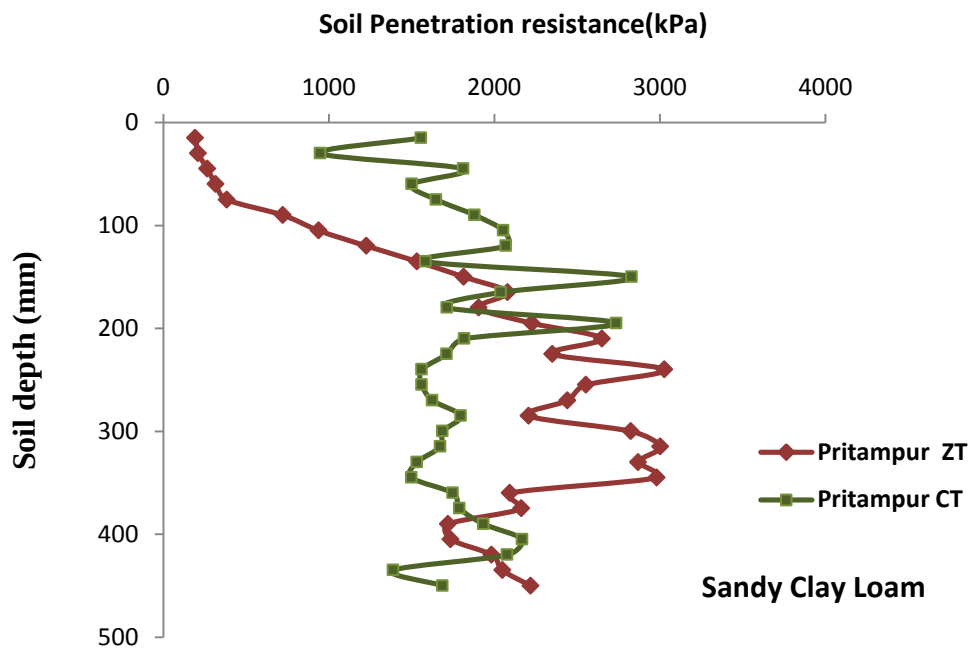


Figure 4. 12 Penetration resistance of soil under zero and conventionally tilled wheat in Jhakauli village (24. 2.2012)

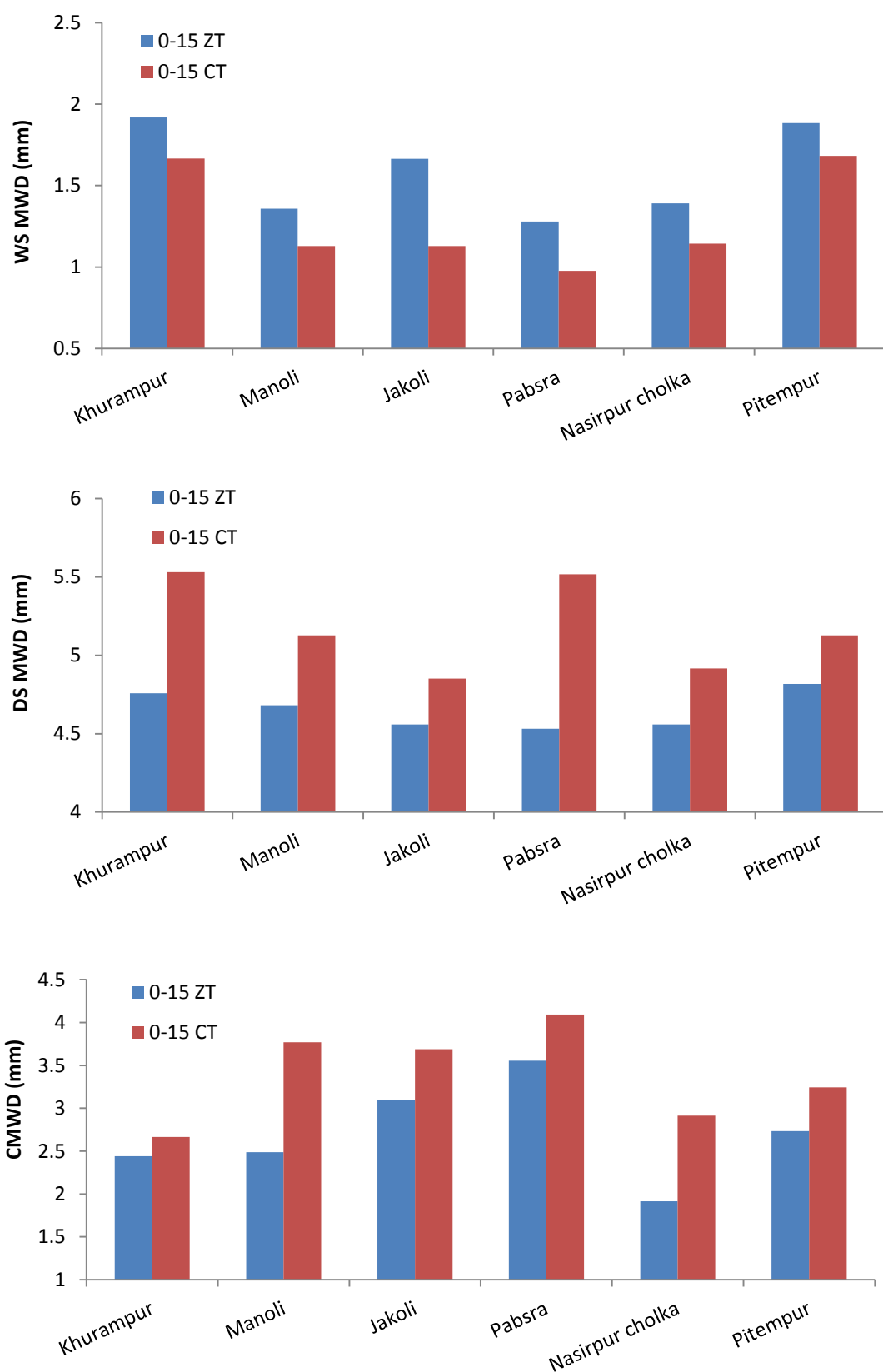


Figure 4.13 WS-MWD, DS-MWD and CMWD under zero tillage and conventional system of surveyed sites